To the University of Wyoming:

The members of the Committee approve the Dissertation of R. Scott Gamo presented on February 26, 2016.

Jeffrey L. Beck, Chairperson

Matthew J. Kauffman, External Department Member

David E. Legg

Roger H. Coupal

Peter D. Stahl

APPROVED:

Scott N. Miller, Head, Department of Ecosystem Science and Management

Francis D. Galey, Dean, College of Agriculture and Natural Resource

EXECUTIVE SUMMARY

Gamo, R. Scott, Effectiveness of Wyoming's Sage-Grouse Core Areas in Conserving Greater Sage-grouse and Mule Deer and Influence of Energy Development on Big Game Harvest, May 2016.

Increasing demand for energy has led to expanded extraction of energy reserves, which, in turn, impact habitats and populations of iconic western species including greater sage-grouse (*Centrocercus urophasianus*), mule deer (*Odocoileus hemionus*), and pronghorn (*Antilocapra americana*) across the West. Policy makers and managers have implemented protections and regulations within designated landscapes to manage focal wildlife species under these conditions. My study evaluates the conservation effectiveness of these landscapes on these focal species in Wyoming within Core Areas established under the Wyoming Governor's Sage-grouse Executive Order (SGEO), implemented in 2008 by then Wyoming Governor Dave Freudenthal.

Greater sage-grouse populations have declined across their range due to human-assisted factors driving large-scale habitat change. In response, the state of Wyoming implemented the SGEO protection policy in 2008 as a voluntary regulatory mechanism to minimize anthropogenic disturbance within defined sage-grouse core population areas. My dissertation consists of two empirical-based chapters that focus on evaluating the effectiveness of the sage-grouse Core Areas in providing conservation to sage-grouse (Chapter 2), and mule deer (Chapter 3), which share habitat with sage-grouse across Wyoming. An additional focus of my dissertation was to investigate the impact of oil and gas development on harvest success for mule deer and pronghorn (Chapter 4). My objectives for Chapter 2 were to evaluate the influence of Core Areas on: 1) oil and gas well pad development, and 2) peak male lek attendance in Core and non-core sage-grouse populations. I conducted my evaluations at the statewide and Western Association of Fish and Wildlife Agencies Management Zone (MZ I and MZ II) scales. I used

ANCOVA modeling to evaluate change in well pad development from 1986–2014 and peak male lek attendance from 958 leks with consistent lek counts within increasing (1996–2006) and decreasing (2006–2013) timeframes for Core and non-core sage-grouse populations. ANCOVA modeling indicated oil and gas well pad development was restricted in Core Areas. Trends in peak male sage-grouse lek attendance were greater in Core Areas compared to non-core areas at the statewide scale and in MZ II, but not in MZ I, during population increase. Trends in total male lek attendance did not differ between core and non-core population areas statewide, in MZ I, or MZ II during population decrease. My results provide support for the effectiveness of Core Areas in maintaining sage-grouse populations, but also indicate the need for restorative actions to increase sage-grouse populations in MZ I.

The conservation of ungulates is becoming more complex as their habitats are subject to continued increases in anthropogenic impacts. Such impacts have been shown to negatively affect habitat use by mule deer. Recent policy has been implemented in western states to conserve habitat and populations of greater sage-grouse. Wyoming's SGEO was implemented in 2008 as a protective mechanism to conserve sage-grouse at a landscape level. This policy has potential to provide protection for non-target species such as mule deer that share substantial habitat with sage-grouse. My objectives for Chapter 3 included: 1) determine whether sage-grouse Core Areas protect Wyoming Game and Fish designated mule deer winter habitat and Hunt Areas from oil and gas development, 2) using fawn:doe ratios, evaluate whether mule deer within sage-grouse Core Areas receive fitness benefits. I used oil and gas well data from the Wyoming Oil and Gas Conservation Commission to compute number of well pads and we computed fawn:doe ratios for mule deer herds derived from Wyoming Game and Fish Department data. Within an ANCOVA modeling framework, I conducted my evaluations across designated mule deer crucial winter ranges (1980–2013) and statewide mule deer Hunt Areas (1995–2013) corresponding with consistently collected well and demographic data, respectively. Mule deer winter ranges that overlapped sage-grouse Core Areas had fewer well pads and displayed less increasing trends in well pads than did winter ranges occurring in non-core areas during 1980–2013. The positive trend (β = 0.00) in fawn:doe ratios (mean = 0.60, range: 0.17–1.50) was higher in hunt areas with $\geq$80% Core Area overlap compared to a slight, but significant negative trend (β = -0.005) in fawn:doe ratios (mean = 0.64, range: 0.14–0.90) in hunt areas with no ($\leq$1%) Core Area overlap from 1995–2013. In addition, the mean for areas with $\geq$70% Core Area overlap exceeded a ratio of 0.66 fawns:doe, a threshold considered indicative of an increasing population. The relative change in fawn:doe ratios may assist in increasing the size of mule deer populations over time. Evidence of protection provided by Core Areas to mule deer winter range habitat and the positive influence on fawn:doe ratios provides additional support for the surrogate role of sage-grouse as an umbrella species for mule deer.

Infrastructure associated with energy development influences hunter access and introduces disturbance activities to landscapes that can influence habitat selection and behavior of ungulates. Consequently, habitat loss and hunter access concerns must be addressed by wildlife managers as they consider management of populations of western big game species including mule deer and pronghorn. Therefore, in Chapter 4, I evaluated whether increased energy development, as quantified through change in well pads, which correspondingly increases roads, has impacted hunter success on mule deer and pronghorn. I included data from 22 mule deer and 34 pronghorn Herd Units across Wyoming from 1980 to 2012. I used number of well pads as a surrogate for energy disturbance. Well pads across mule deer Herd Units increased from 1,040 in 1980 to 9,689 in 2012, and well pads in pronghorn Herd Units increased from

1,359 to 15,251 during the same time period. My results indicated that hunter success (%) for mule deer in Wyoming was positively associated with number of well pads and a decrease in hunter effort, whereas pronghorn hunter success in Wyoming was unaffected by increasing well pads. I was able to identify a change in mule deer harvest success attributable to increasing energy development; however, harvest statistics were not informative in identifying impacts from energy development on pronghorn populations.

EFFECTIVENESS OF WYOMING'S SAGE-GROUSE CORE AREAS IN CONSERVING GREATER SAGE-GROUSE AND MULE DEER AND INFLUENCE OF ENERGY DEVELOPMENT ON BIG GAME HARVEST

By

R. Scott Gamo

A dissertation submitted to the Department of Ecosystem Science and Management

and the University of Wyoming

in partial fulfillment of the requirements

For the degree of

DOCTORATE OF PHILOSOPHY

In

RANGELAND ECOLOGY AND WATERSHED MANAGEMENT

Laramie, Wyoming

May 2016

ACKNOWLEDGMENTS

I thank all who have contributed to wildlife management in the state of Wyoming, which, as a result of their efforts, has enabled me to evaluate my questions relating to the interactions of policy and management. My research would not have been possible without the efforts of a multitude of field personnel from Wyoming Game and Fish Department (WGFD), Bureau of Land Management (BLM), and other entities in collecting lek attendance data, herd counts, and harvest data over the long timeframe I reviewed. I first thank Dr. Jeff Beck who served as my committee chair and graduate advisor, who was willing to take on an experienced mid-career professional as a student. It was interesting comparing our academic versus management career tracks across years especially because we had in common interactions with agencies, habitats, species, and states. I commend my graduate committee Dr. Jeff Beck, Dr. David Legg, Dr. Matt Kauffman, Dr. Pete Stahl and Dr. Roger Coupal, for giving me their time, thoughts, and advice. I especially acknowledge David Legg for his assistance with statistical analyses and Drs. Matt Kauffman and Jeff Beck for study design improvements. I appreciate Dr. Mark Rumble, Dr. Josh Millspaugh, and Kurt Smith for providing additional design thoughts and paper reviews. I also thank WGFD staff including Mary Flanderka, Tom Christiansen, John Emmerich, and John Kennedy for their support. I also thank Troy Gerhardt from WGFD and my GIS technician, Brian Brokling, for their help with GIS layers and data management. Finally, I thank my wife Paige and son Ayden for their patience and support as I completed this effort.

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CHAPTER ONE

Introduction

Wildlife conservation is increasingly complex as habitats continue to be subject to expanding natural resource extraction, urbanization, industrial infrastructure, and agricultural expansion. For example, the global demand for energy is estimated to increase by 40% within the next 20 years expanding oil, gas, coal, and renewable energy development (International Energy Agency 2015). This increase in demand for energy resources is forecast to result in >200,000 km^2 of land utilized by various forms of energy development in the United States by 2035 (McDonald et al. 2009). Degradation and loss of sagebrush (*Artemisia spp*.) habitat (Connelly and Braun 1997, Connelly et al. 2004) are the primary drivers leading to an approximate 50% loss of greater sage-grouse (*Centrocercus urophasianus*, hereafter, sage-grouse) historical range since pre-settlement of the North American West (Schroeder et al. 2004). The loss and fragmentation of habitats and subsequent populations of sage-grouse have led to their consideration as a species of heightened concern. In March 2010, the U.S. Fish and Wildlife Service (USFWS) listed greater sage-grouse as a candidate species, warranted but precluded from listing at that time because other species were under severe threat of extinction as threatened or endangered under the Endangered Species Act (ESA) of 1973 (USFWS 2010). The USFWS identified habitat loss and fragmentation from wildfire, invasive plants, energy and infrastructure development, urbanization, and agricultural conversion as the primary threats to the species throughout its range. Inadequacy of regulatory mechanisms and conservation measures in state and federal land management plans was also identified as one of the major factors in the USFWS's 2010 finding on sage-grouse. However, in September 2015 the USFWS found the greater sage-grouse unwarranted for listing primarily due to threats being significantly reduced through federal, state, and private land conservation plans across its range (USFWS 2015).

A listing decision for sage-grouse would likely have considerable economic consequences for Wyoming given the role extractive natural resources play in driving the state's economy. Furthermore, the 2010 USFWS listing decision ranked infrastructure associated with energy development second among threats confronting current populations of sage-grouse (USFWS 2010). A change in the legal status of greater sage-grouse under the ESA could have affected land surface uses including natural resource extraction industries, agriculture, recreation, and other land-use activities. Thus, in Wyoming, a "regulatory mechanism" or natural resource policy to protect the bird's habitat and populations titled the "Sage-Grouse Core Area Strategy and Governor's Executive Order for Sage-Grouse (SGEO)" was developed and initially implemented in August 2008 by then Governor Dave Freudenthal (State of Wyoming 2008). In 2007, Governor Freudenthal held a forum of representatives of state and federal agencies, non-governmental organizations, and industries, the outcome of which was the Sage-grouse Implementation Team (SGIT), charged with developing a regulatory mechanism for the protection and conservation of sage-grouse within Wyoming. One of the SGIT's first tasks was to designate an area in which the regulatory mechanism could be implemented. As described below, this area designation was essential in providing the basis for protection of sage-grouse and their habitats in Wyoming.

The SGIT utilized biological data from Doherty et al. (2010, 2011) while avoiding areas of current major energy development to construct a sage-grouse core protection area map for Wyoming (Figure 1). Doherty et al. (2010, 2011) used the density of sage-grouse leks to develop the core region concept for sage-grouse in Wyoming. Core regions in the eastern portion of sage-grouse range, which includes Wyoming, contain 25%, 50%, 75%, and 100% of the breeding population within 5%, 12%, 30%, and 60% of the eastern range distribution of sage-grouse, respectively (Doherty et al. 2011). Doherty et al.'s (2010, 2011) model did not take into account late brood-rearing and wintering life stages. However, Fedy et al. (2012) offered additional support for Doherty's model reporting 85% of summer locations and 65% of wintering locations from studies across Wyoming occurred within the 75% predicted core sage-grouse breeding areas in the State.

With Core Areas delineated from the core regions, the implementation team focused on regulatory mechanisms to be applied within core protection area designations. The result was the Governor of Wyoming's SGEO 2008-02 (State of Wyoming 2008). This order provided a process for protecting sage-grouse within 31 Core Areas consisting of approximately 24% of the surface land area of the state of Wyoming (Figure 1). These protection areas as mapped encompassed an estimated 82% of the male sage-grouse breeding population within the State (Wyoming Game and Fish Department, Cheyenne, unpublished data). Further refinements of Core area boundaries and Governor Freudenthal's executive order in 2010 and subsequent reissuing of the order by Governor Matt Mead resulted in Sage Grouse Executive Order 11-05 (State of Wyoming 2011). In addition, the Bureau of Land Management (BLM) issued an Instruction Memorandum (IM; BLM 2012) for sage-grouse conservation in early 2012, which closely parallels guidance provided by the Wyoming SGEO. Other western states are also evaluating and implementing approaches to sage-grouse conservation (e.g., Oregon Department of Fish and Wildlife 2011; State of Idaho 2012*a*, 2012*b*; State of Montana 2014, State of Nevada 2014, Stiver 2011).

Contained within the Wyoming SGEO and the BLM IM are protective stipulations for sage-grouse, based upon their biological needs, and a GIS-based (Geographic Information System) procedure for determining levels of anthropogenic disturbance on the landscape within Core Areas (State of Wyoming 2011:Appendix B). Per direction of the SGEO, such disturbances are threshold limited, thus effectively limiting anthropogenic activities and disturbances within Core Area boundaries. For example, within sage-grouse Core Areas, the number of surface disturbances should not exceed an average of 1 per 2.6 km^2 (640 ac) across the disturbance analysis area as defined in the SGEO (State of Wyoming 2011:Appendix B). A disturbance analysis area is determined by placing a 6.44 km (4-mi) buffer around the proposed project (or disturbance). Occupied sage-grouse leks intersected by this initial 6.44-km buffer then receive their own 6.44-km buffer. The entirety of this merged buffer area, which only occurs within the boundary of the Core Area, then becomes the disturbance analysis area (State of Wyoming 2011). Further, total accumulated surface area existing and proposed within an analysis area should not exceed 5% of the disturbance analysis area. Seasonal stipulations are applied including no surface occupancy within1 km of occupied or active leks, and a restriction of human activity within the entirety of the core population area from 15 March to 30 June. The seasonal stipulation is intended to protect breeding, nesting, and early brood-rearing activities of sage-grouse.

The Governor of Wyoming's SGEO, as a regulatory mechanism, was designed to conserve and maintain sage-grouse populations and habitat through a detailed process of planning and managing energy development and other surface disturbing activities within the boundaries of sage-grouse Core Areas. By design, this process essentially minimizes surface disturbance size and densities at a landscape scale within Core Area boundaries. As this policy is a landscape approach occurring across Wyoming, there is potential for this policy to conserve or protect other wildlife species (Gamo et al. 2013).

Wyoming provides habitat to some of the largest populations of wild ungulates in North America including pronghorn (*Antilocapra americana*), mule deer (*Odocoileus hemionus*), elk (*Cervus canadensis*), Rocky Mountain bighorn sheep (*Ovis canadensis*), and Shiras moose (*Alces alces shirasi*). In particular, in high population years, Wyoming provides habitat to over 500,000 pronghorn and 425,000 mule deer (unpublished WGFD data, Cheyenne). In addition, Wyoming has immense natural resources in the form of extractive products such as oil and gas, coal, uranium, bentonite, and trona, in addition to renewable energy such as wind and solar. Invariably, these resources overlap. Mule deer have experienced impacts due to energy development (Sawyer et al. 2006, 2009, Lendrum et al. 2012, Sawyer et al. 2013). Because mule deer share sagebrush habitats alongside sage-grouse there is high potential this species may benefit from the protective measures contained within the SGEO. Thus, an unanticipated circumstance of implementation of the SGEO is its potential to conserve habitats, through designation of Core Area, for other sagebrush obligate or co-occurring species (Gamo et al. 2013, Copeland et al. 2014). For instance, many mule deer herds in Wyoming are migratory and utilize sagebrush basins for wintering habitat as they move across a gradient from high elevation summer habitats (Sawyer et al. 2006, 2009, 2011). Approximately 33% of mule deer crucial winter ranges in the state overlap sage-grouse Core Areas (Figure 2; Wyoming Game and Fish Department [WGFD] unpublished data, Cheyenne, WY). In contrast to sage-grouse, mule deer have no similar habitat based regulatory mechanism to conserve their habitats. Rather, the WGFD has developed a set of protective seasonal stipulations and best management practices designed to help minimize adverse impacts to mule deer populations and their habitats (WGFD

Oil and Gas Recommendations, WGFD Wind Recommendations; Cheyenne, WY, WGFD 2009). However, these practices have no statutory or regulatory enforcement authority and may be waived by land management agencies.

Presumably, greater restrictions placed on development and other anthropogenic activities as part of sage-grouse core population area management in Wyoming should yield benefits to large, mobile species such as mule deer. Potential benefits to mule deer provided by greater protections in sage-grouse Core Areas may be similar to those discussed in Sawyer et al. (2009). They found reducing truck traffic by piping oil and gas waste fluids through pipelines rather than by trucking the material out of winter ranges resulted in greater use of these areas by mule deer than when only trucking was used. Reduced truck traffic (i.e., reduced human activity) lessened negative impacts on wintering mule deer (Sawyer et al. 2009). Copeland et al. (2014) suggested Core Area protections combined with private land easements provided greater protections for mule deer migration routes. Polfus et al. (2011) noted that when human activity was much lessened around mines, cabins, and hunting camps (periods of low use), caribou (*Rangifer spp*.) were much closer to these areas than during periods of high human activity. Research from northeastern Wyoming found elk avoided areas of active gas development where elk selected areas with greater woody vegetative cover, more rugged terrain, and greater distance from roads (Buchanan et al. 2014). This study recommended reducing traffic, providing woody escape cover, and maintaining areas of refugia to minimize impacts from development. With implementation of the SGEO, surface disturbances due to energy development should be fewer and smaller within core population areas than non-core areas.

Modern conservation is increasingly reliant on efforts to conserve surrogate species to provide benefits for multiple species. Noss (1990:360-361) defined surrogate species as "a species with large area requirements, which if given sufficient protected habitat area, will bring many other species under protection." Umbrella species are a type of surrogate species that may provide conservation benefits to other species (Noss 1990). In Wyoming, sage-grouse may well function as an umbrella species for other sagebrush-dependent wildlife species (Rich and Altman 2001, Rowland et al. 2006, Hanser and Knick 2011, Gamo et al 2013). The suggestion that sage-grouse serve as an umbrella species was proposed by Rowland et al. (2006) for the Great Basin. They found sage-grouse habitat overlapped with 50% of pronghorn habitat in the Great Basin. In Wyoming, approximately 45% of identified pronghorn crucial winter range (a sensitive seasonal habitat) alone overlaps with sage-grouse core population areas and a large portion of other seasonal ranges used by pronghorn also overlap core population areas (WGFD, unpublished data).

Surface disturbances such as roads, pipelines, oil and gas well pads, and other man-made features and activities are known to impact habitats of caribou (*Rangifer tarandus*; Cameron et al. 2005, Vors et al. 2006, Sorensen et al. 2007, Polfus et al. 2011), elk (Thomas et al. 1979, Lyon 1983, Kuck et al. 1985, Millspaugh et al. 2000, Rowland et al. 2000, Rumble and Gamo 2011, Webb et al. 2011, Buchanan et al. 2014), mule deer (Rost and Bailey 1979, Thomas et al. 1979, Medcraft and Clark 1986, Gamo and Anderson 2002; Sawyer et al. 2006, 2009; Lendrum et al. 2012, Sawyer et al. 2013), and pronghorn (Ockenfels et al. 2000, Gamo and Anderson 2002, Sheldon 2005, Gavin and Komers 2006, Beckman et al. 2012). Networks of road infrastructure in energy developments facilitate transportation of material, equipment, and personnel to and from well pads and other infrastructure points.

In addition to affecting ungulate habitat use and behavior, roads may impact hunter distributions through increasing or limiting hunter access to potential hunting areas (Gratson and

Whitman 2000, Lebel et al. 2012). Gratson and Witman (2000) found that as hunter densities increased due to more road access, elk harvest success decreased. Unsworth et al. (1993) and others (Cole et al. 1997, Hayes et al. 2002, McCorquodale et al. 2003) found elk mortality, mainly due to harvest, increased with increased road and hunter densities. Increased road networks within intensively farmed areas likely contributed to greater white-tailed deer (*O. virginianus*) vulnerability to hunting (Brinkman et al. 2004).

Traditional means of evaluating natural resource extraction related impacts to ungulates has included time and funding intensive studies, which often use GPS- or radio-collared animals to evaluate potential changes in habitat selection relative to use of developed areas (e.g., Sawyer et al. 2006, 2009; Buchanan et al. 2014). Assessing impacts of exposure to energy development infrastructure on ungulate fitness has been more difficult (e.g., Taylor et al. 2016). However, harvest data are readily available and collection of these data is generally integrated into annual monitoring plans by state wildlife agencies to obtain critical information to manage big game populations. The WGFD, similar to other western state wildlife agencies, collects a variety of herd and hunt statistics including harvest (%; hunter success), hunter effort (days until harvest), herd age ratio, and number of hunters per Herd Unit on a yearly basis (Rupp et al. 2000, Rabe et al. 2002). Evaluating ungulate population response to anthropogenic impacts such as natural resource development may be possible through correlation of anthropogenic infrastructure with annual harvest and herd status data. Big game populations are increasingly exposed to higher densities of surface disturbances in states such as Wyoming where natural resource development continues to expand. Associated increases in roads may increase hunter access but may also increase avoidance of habitat by big game species. Analyses of these data may provide managers with meaningful information to better manage ungulate populations in landscapes facing increasing natural resource development.

The aim of my research was to provide an empirical examination of a natural resource policy aimed at protecting sage-grouse. The Wyoming SGEO provided a unique opportunity to study whether policy protected landscapes can be effective on the target species and potentially on non-target species. Finally, I evaluated the utility of using long-term agency collected datasets to determine oil and gas development related impacts to endemic ungulate species. In Chapters 2 and 3, my co-authors and I document the impact of sage-grouse Core Areas on the populations and habitat of a target species, the sage-grouse, and a non-target species, the mule deer using multiple analytical tools. My objectives for Chapter 2 included: 1) evaluating oil and gas well pad development within Core Area, and 2) comparing total peak male sage-grouse lek attendance in Core Area and non-core areas. My objectives for Chapter 3 were to: 1) quantify oil and gas development in both mule deer crucial winter range and WGFD Hunt Areas in respect to Core Area overlap, and 2) using fawn:female ratios , evaluate whether mule deer populations overlapping Core Areas received fitness benefits. As a direction separate from the SGEO yet related to oil and gas impacts on wildlife, my primary objective for Chapter 4 evaluate whether increased energy development, as quantified through change in well pad densities, has impacted hunter success on mule deer and pronghorn in Wyoming.

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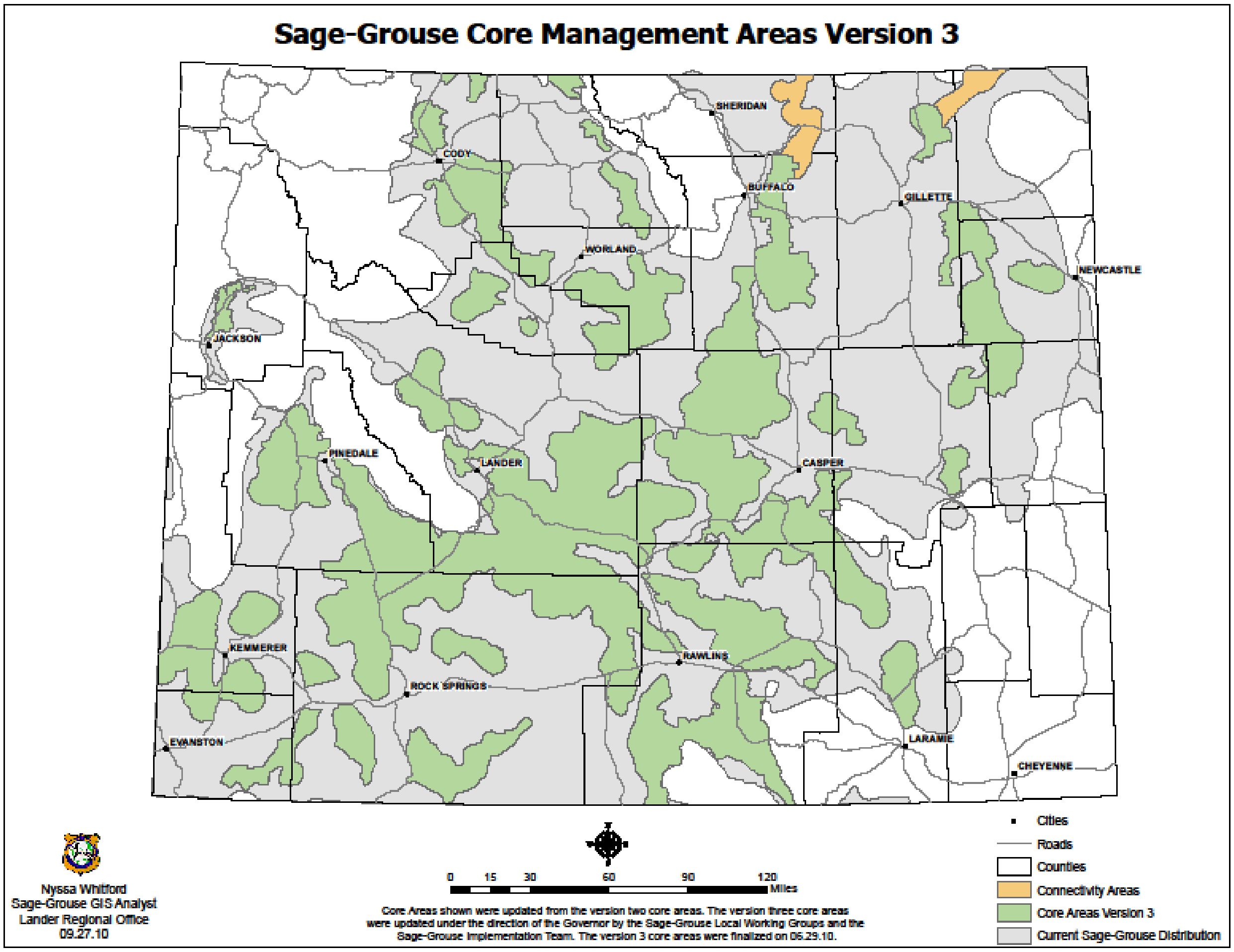

Figure 1. Sage-grouse core population areas across Wyoming. Map version 3 (27 Sep 2010) prepared by Nyssa Whitford, Wyoming Game and Fish Department, Lander.

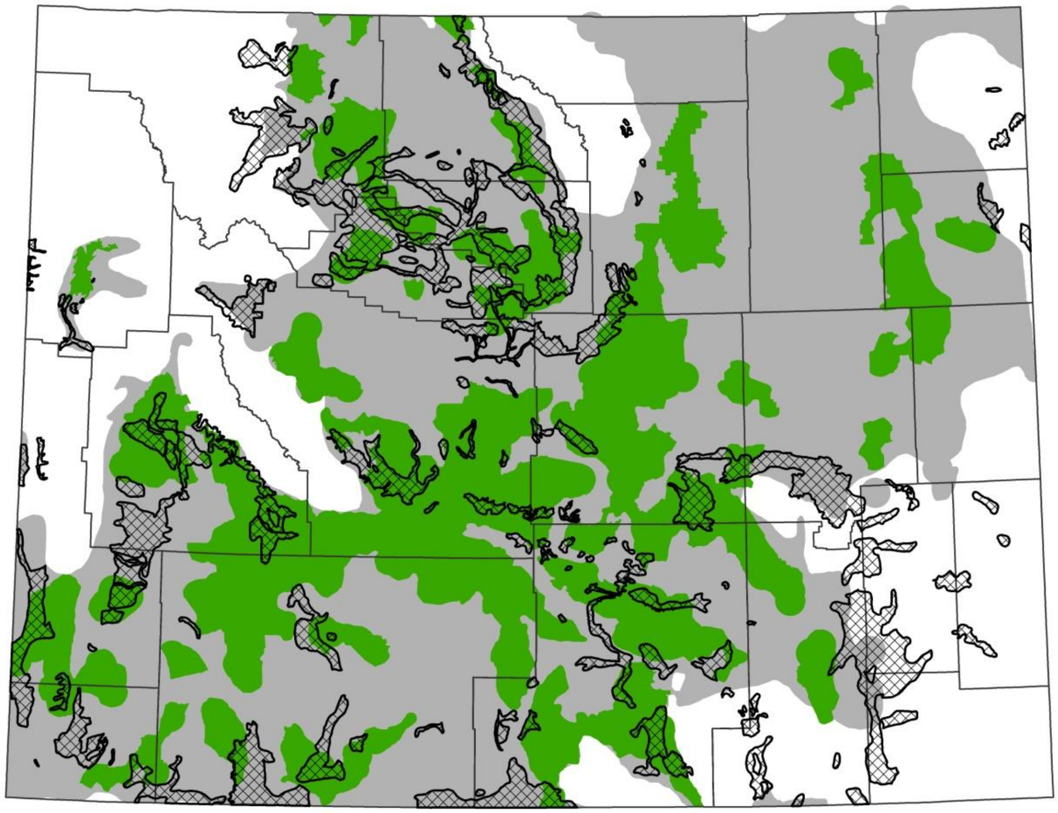

Figure 2. Location of mule deer crucial winter range (hashed polygons) overlaying sage-grouse Core Areas in green in Wyoming. Gray shading indicates current range of sage-grouse (Schroeder et al. 2004). Mule deer and Core Area delineations by Wyoming Game and Fish Department (Core Area Ver. 3, State of Wyoming 2010).

CHAPTER TWO

Effectiveness of Wyoming's Sage-Grouse Core Areas: Influences on Energy Development and Male Sage-grouse Lek Attendance

R. S. Gamo· J. L. Beck

R. Scott Gamo (corresponding author)
Wyoming Game and Fish Department and Department of Ecosystem Science and Management, University of Wyoming
Cheyenne, WY 82005
E-mail:scott.gamo@wyo.gov; Phone-307-777-4509

Jeffrey L. Beck
Department of Ecosystem Science and Management
University of Wyoming
Laramie, WY 82071

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Acknowledgments

Our research would not have been possible without the efforts of WGFD, BLM, and other biologists in collecting lek attendance data we used to frame our analyses. We thank Tom Christiansen from WGFD for providing access to the Wyoming sage-grouse lek database. We especially acknowledge David Legg, University of Wyoming, for his critical assistance with statistical analyses. Matthew Kauffman, Roger Coupal, and Peter Stahl, University of Wyoming, and Joshua Millspaugh, University of Missouri-Columbia, all provided helpful insights in regard to study design and analyses. We also thank Mary Flanderka, John Emmerich, John Kennedy, and Troy Gerhardt from WGFD for their insights. Mark Rumble, U.S. Forest Service Research Ecologist, provided an outside review of an earlier draft, and Brian Brokling processed spatial data for use in analyses. Our research was supported by WGFD Grant Number 0020011.

Abstract:

Greater sage-grouse (*Centrocercus urophasianus*) populations have declined across their range due to human-assisted factors driving large-scale habitat change. In response, the state of Wyoming implemented the Sage-grouse Executive Order (SGEO) protection policy in 2008 as a voluntary regulatory mechanism to minimize anthropogenic disturbance within defined sage-grouse core population areas. Our objectives were to evaluate areas designated as SGEO Core Areas on: 1) oil and gas well pad development, and 2) peak male lek attendance in core and non-core sage-grouse populations. We conducted our evaluations at statewide and Western Association of Fish and Wildlife Agencies management zone (MZ I and MZ II) scales. We used ANCOVA modeling to evaluate change in well pad development from 1986–2014 and peak male lek attendance from 958 leks with consistent lek counts within increasing (1996–2006) and decreasing (2006–2013) timeframes for Core and non-core sage-grouse populations. Oil and gas well pad development was restricted in Core Areas. Trends in peak male sage-grouse lek attendance were greater in Core Areas compared to non-core areas at the statewide scale and in MZ II, but not in MZ I, during population increase. Trends in peak male lek attendance did not differ between Core and non-core population areas statewide, in MZ I, or MZ II during population decrease. Our results provide support for the effectiveness of the Core Areas in maintaining sage-grouse populations, but also indicate the need for increased conservation actions to improve sage-grouse population response in MZ I.

Keywords: *Centrocercus urophasianus*, Greater sage-grouse, Core Area, Impact assessment, Natural resource policy, Population monitoring, Wyoming Sage-grouse Executive Order

Introduction

Greater sage-grouse (*Centrocercus urophasianus*; hereafter sage-grouse) have declined from historical numbers across the western United States and Canada (Garton et al. 2011). Declines include an overall annual rate of 2% from 1965–2003 (Connelly et al. 2004) and a 56% decline in males counted on 10,060 leks (i.e., spring breeding grounds) in 11 western states from 2007 (109,990) to 2013 (48,641; Garton et al. 2015). However, sage-grouse populations are cyclic (Fedy and Doherty 2011, Fedy and Aldridge 2012) and counts indicate range-wide increases in 2014 and 2015 (Nielson et al. 2015). Coincidentally, the distribution of sage-grouse has contracted approximately half from historical range (Schroeder et al. 2004) primarily due to degradation and loss of sagebrush (*Artemisia* spp.) habitat (Connelly et al. 2004, U. S. Fish and Wildlife Service 2010). Infrastructure and activities associated with natural resource extraction, which are most prominent in the eastern portion of sage-grouse range, adversely impact sage-grouse (Braun et al. 2002, Holloran and Anderson 2005, Walker et al. 2007, Harju et al. 2010, Holloran et al. 2010, USFWS 2010, LeBeau et al. 2014). Energy development has been shown to specifically impact male sage-grouse lek attendance (Walker et al. 2007, Harju et al. 2010, Gregory and Beck 2014), lek persistence (Walker et al. 2007, Hess and Beck 2012), recruitment of yearling male and female grouse to leks (Holloran et al. 2010), nest initiation and site selection (Lyon and Anderson 2003), nest survival (Dzialak et al. 2011, LeBeau et al. 2014), chick survival (Aldridge and Boyce 2007), brood survival (LeBeau et al. 2014, Kirol et al. 2015*a*), summer survival of adult females (Dinkins et al. 2014a), early brood-rearing habitat selection (Dinkins et al. 2014b), adult female summer habitat selection (Fedy et. al. 2014, Kirol et al. 2015*a*), and adult female winter habitat selection (Doherty et al. 2008. Carpenter et al. 2010, Dzialak et al. 2013, Smith et al. 2014, Holloran et al. 2015).

The cumulative effects of energy-related impacts in the eastern range, and other impacts such as invasive plant species and altered fire regimes in the western portion of sage-grouse range, have led to consideration of the sage-grouse for threatened or endangered species listing under the Endangered Species Act of 1973 by the United States Fish and Wildlife Service ([USFWS] 2010, 2015). The March 2010 USFWS listing decision designated the greater sage-grouse as a candidate species, warranted for listing, but precluded from listing at that time because other species were under severe threat of extinction (USFWS 2010). In response to anticipated threatened or endangered species listing, the State of Wyoming developed a strategy through an executive order issued by the Governor of Wyoming to conserve sage-grouse. The Wyoming Governor's Executive Order for Sage Grouse (SGEO) was first implemented in late 2008 and provides a voluntary regulatory mechanism designed to limit and/or minimize anthropogenic disturbance within defined boundaries identified as sage-grouse population areas (State of Wyoming 2008; Doherty et al. 2010, 2011[Fig. 1]). A major component of this mechanism is the establishment of defined conservation areas for sage-grouse termed Core Area.

The SGEO, as a state-driven regulatory mechanism, was designed to conserve and maintain sage-grouse populations and habitat through a detailed process of planning and managing energy development and other surface disturbing activities within the boundaries of sage-grouse Core Areas. The goal was to protect two-thirds of the sage-grouse population within the state as identified by peak male lek attendance (B. Budd, Wyoming Sage-Grouse Implementation Team [SGIT], personal communication). This effort assimilated the highest sage-grouse density areas identified by Doherty et al. (2010) as they were identified as the most productive habitats for sage-grouse in Wyoming In addition, the mapping of Core Areas considered current and potential energy development and encapsulated areas historically low in production (Gamo 2016; figure 2). The end result included approximately 82% of Wyoming's total male sage-grouse population as measured by peak male lek attendance (unpublished data, Wyoming Game and Fish Department [WGFD]). By design, the SGEO process minimizes surface disturbance size and densities at a landscape scale within Core Area boundaries. Policy makers utilized research evaluating the impacts of energy extraction on sage-grouse to develop the specifics of the SGEO. Three parameters were adopted forming the basis for conservation measures within the SGEO: 1) disturbances should not occur within 1 km (0.60 mi) of occupied leks, 2) disturbance density should not exceed 1 per 2.6 km^2 (640 ac) within the analysis area (e.g., Holloran 2005 Doherty 2008) and 3) total disturbance acreage should not exceed 5% of the analysis area (State of Wyoming 2011). In contrast, sage-grouse populations outside of Core Areas (i.e., non-core areas) are not subject to these conservation measures. Prescribed stipulations in non-core areas include maintaining a 0.40 km (0.25 mi) buffer of controlled surface use around leks, and a 3.33 km (2.0-mi) buffer with a seasonal timing stipulation (15 Mar–30 Jun) around leks. Both of these stipulations are subject to potential modification or waiver (State of Wyoming 2011).

Wyoming's governor requested a review of the progress and effectiveness of the SGEO to occur every 5 years (State of Wyoming 2011). In addition, the USFWS conducts 5-year status reviews of candidate species including sage-grouse (USFWS 2010). Thus, the State of Wyoming has a need to provide an accurate and accountable examination of the effectiveness of the SGEO in maintaining sage-grouse populations in Wyoming. The effectiveness of the SGEO is dependent upon several factors. First, whether the lands encompassed by Core Area benefit sage-grouse. Second, how well have the parameters been applied. This is particularly tenuous as the SGEO is a Governor's order; not a rule of legislated law. And, finally, are the parameters, which are based on science, truly effective when applied at a landscape scale. The success of the SGEO has greater ramifications than just for Wyoming. Other western states are also implementing approaches to sage-grouse conservation within their jurisdictions (e.g., Oregon Department of Fish and Wildlife 2011; State of Idaho 2012*a*, 2012*b*; State of Montana 2014, State of Nevada 2014, Stiver 2011). The Bureau of Land Management also recently incorporated additional protections for sage-grouse into their current and updated land management plans (BLM 2012).

Since it was initiated in 2008, there has not been an evaluation of whether Core Areas designated by the SGEO are effective in conserving sage-grouse in light of continued energy development. The designation of Core Areas is the major component of the SGEO as Core Areas provide the habitat across the state where the SGEO conservation measures are applied. Further, lands encompassed by Core Area likely served as functional Core Area even prior to policy designation as evidenced by historically high densities of sage-grouse (Doherty et al. 2010, WGFD unpublished data) and minimal development through time (Gamo 2016). Therefore, the focus of our study was on assessing whether Wyoming Core Areas benefit sage-grouse populations. Our objectives included: 1) evaluating oil and gas well pad development within Core Area, and 2) comparing total peak male sage-grouse lek attendance in Core Area and non-core areas. In line with existing habitat quality at time of SGEO implementation, we predicted that rate of energy development within sage-grouse Core Area would be lower compared to non-core areas. We further predicted oil and gas development in the Core Areas would exhibit less expansion after SGEO implementation compared to non-core area. We also predicted that sage-grouse populations within Core Area would exhibit more robust male lek attendance than non-core area grouse populations. To test these predictions, we evaluated well pad numbers and male sage-grouse lek attendances between core and non-core population areas at statewide and management zone scales. Finally, we provide initial information related to disturbances within Core Area to assess short-term progress of SGEO implementation. Our paper provides the first assessment of the measured effectiveness of the Wyoming's Core Area designations, which should be of great value to managers and scientists considering implementing other landscape-scale species conservation programs.

Materials and Methods

Study Area

Our study area encompassed the range of sage-grouse across Wyoming. Within this delineated range, 31 Core Areas have been designated and mapped (State of Wyoming 2011; Fig. 2). Core Areas occupy approximately 24% of the land area of Wyoming and generally reside in the major basins found between mountain ranges including the Wyoming Basins (Rowland and Leu 2011) in the western and central portions of the state and the Powder River Basin in the northeast (Knight et al. (2014). Sage-grouse Core Areas vary in size from a minimum of 41 km^2 to a maximum of 18,587 km^2. The Western Association of Fish and Wildlife Agencies (WAFWA) mapped the entire sage-grouse range into 7 sage-grouse management zones based on ecological conditions (MZ; Stiver et al. 2006). The Great Plains-Management Zone-MZ I and the Wyoming Basin-MZ II occur in Wyoming. The northeastern portion of Wyoming, including the Powder River Basin and the plains extending east and north from the northern Laramie Mountains to the state line bordering South Dakota lie within MZ I. The remainder of the state (excluding the southeastern plains, which are not inhabited by sage-grouse) including the sagebrush dominated basins west of the Laramie and Bighorn Mountain Ranges fall within MZ

II (Rowland and Leu 2011). From 2010–2014, MZ II included 36.8% of range-wide breeding male sage-grouse (compared to 12.4% in MZ I; Doherty et al. 2015) and contains the second largest area of suitable habitat range-wide (Wisdom et al. 2011).

Northeastern Wyoming rangelands, including the Powder River Basin, consist of sagebrush dominated shrub steppe integrating with mixed grass prairie towards the South Dakota border (Knight et al. 2014). Sagebrush steppe vegetation consists of Wyoming big sagebrush (*A. tridentata wyomingensis*, silver sagebrush (*A. cana*). and a diverse understory of herbaceous plants. Common native grasses include blue grama (*Bouteloua gracilis*), bluebunch wheatgrass (*Pseudoroegneria spicata*), and non-native grasses include crested wheatgrass (*Agropyron cristatum*) and cheatgrass (*Bromus tectorum*; Thelenius et al. 1994). Rocky Mountain juniper (*Juniperus scopulorum*) and ponderosa pine (*Pinus ponderosa*) occur on rocky uplifts and in river drainages.

The Wyoming Basins in the western part of the state consist of multiple basins between mountain ranges. Major basins include the Bighorn, Great Divide, Green River, and Shirley. Vegetation in these basins is much more dominated by sagebrush than northeast Wyoming and consist of sagebrush steppe dominated by Wyoming big sagebrush with areas of black (*A. nova*) and low sagebrush (*A. arbuscula*; Rowland and Leu 2011, Knight et al. 2014). Common grasses include bluebunch wheatgrass and needle and thread (*Hesperostipa comata*). Invasive grass species such as cheatgrass are becoming more common in the Wyoming Basins (Knight et al. 2014).

Methods

Wells Pads

We obtained data on numbers of wells from the Wyoming Oil and Gas Conservation Commission (WOGCC) oil and gas well database dating from 1986 through 2014 (WOGCC 2014). Harju et al. (2010) used well pads as a more easily measureable surrogate for energy impacts. Similarly, we tabulated wells located within sage-grouse range and only included active wells; wells that were plugged, abandoned or not active were removed from further analysis (e.g., Holloran 2005). Wells were also assigned to Core Area or non-core area. We calculated average well pad size based upon the average size of 100 randomly chosen well pads digitized in GIS. Based upon the average well pad size we calculated an average well pad diameter of 120 m (mean = 0.011 km^2). We computed the number of well pads by placing a 60-m radius circle around each well head. Using GIS, anywhere a 60-m radius touched or overlapped another 60-m radius that intersection was merged into one well pad. Finally, we determined the number of well pads at a statewide level, within MZ I and II for each year 1986 through 2014.

Male Sage-grouse Lek Attendance

Our analyses used total (i.e., sum of all lek counts in each analysis scale per year) annual peak male counts, which is the statistic used to monitor sage-grouse populations per the Wyoming SGEO (B. Budd, Wyoming SGIT, personal communication). We calculated annual peak male lek attendance using the WGFD sage-grouse lek count database from 1996 through 2014. Our analyses did not rely on average males per lek, which is a common statistic used to monitor trends in sage-grouse populations (e.g., Walker et al. 2007, Harju et al. 2010, Gregory and Beck 2014). However, for comparison we also calculated and report average males per lek from 1996 through 2014 among our sampled leks. Lek count procedures were standardized in 1996 and protocols consisted of 3 separate counts for each lek spaced at least 7 days apart from March through May (Connelly et al. 2003, 2004). The peak count was the maximum recorded number of males of the 3 counts. We only included leks considered active by WGFD definition (e.g., documented attendance of 2 or more individuals within a 10-year time frame). Leks were identified as Core Area leks or non-core leks according to their location within a Core Area or outside of those areas as described in the SGEO. We evaluated total peak male sage-grouse lek attendance statewide and for WAFWA MZs I and II. These designations were chosen as they correspond to state policy (statewide) and potential regulatory decisions at the federal level (MZs). We summed total peak male lek attendance in Core Area and non-core area at the statewide and WAFWA MZ scales. Statewide estimates included leks aggregated from all 31 individual core population areas.

Recognizing the strong cyclic nature of sage-grouse populations in Wyoming (Fedy and Doherty 2011, Fedy and Aldridge 2012) we chose to evaluate differences between Core Area and non-core area birds separately during periods of population increase (1996–2006) and decline (2006–2013). Core Areas were originally identified based upon high lek densities with abundant grouse populations, high quality habitat (Doherty et al. 2010), and relative exclusion from development (B. Budd, pers. comm., Gamo 2016). Fedy and Aldridge (2012) noted sage-grouse populations in Wyoming experienced a period of increase from 1996 through 2006. Correspondingly, a downward trend was observed from 2006 through 2013 (unpublished data, WGFD, Nielson et al. 2015). Therefore, our evaluation of Core Area influence on grouse includes years prior to the SGEO policy designation and allows the opportunity to evaluate implications of the chosen landscape during both increasing and decreasing phases of a sage-grouse population cycle.

To provide insight on the effectiveness of the Wyoming SGEO policy, we report data provided by the WGFD in response to the 2014 USFWS greater sage-grouse data call as part of their Endangered Species Act listing determination. These data provide a short-term description of SGEO related features obtained from site specific impact analyses conducted by development proponents and state and federal agencies that were reviewed for SGEO policy conformance by the WGFD. Data were available only for the years 2012 through 2014 which correspond to the implementation of a statewide SGEO database system.

Statistical Analysis

We utilized Analysis of Covariance (ANCOVA; PROC REG, SAS 9.4, SAS Institute, Cary, NC) to compare trends in well pad development between Core Area and non-core area at statewide and management zone scales. We compared the main effects of study area (i.e., Core Area or non-core area) with time being the covariate in each ANCOVA. In our design, well pads in Core Area constructed after 2009 constituted the treatment whereas non-core well pads after 2009 served as the control. Well pads within Core Areas from 1986 through 2008 served as before or pre-treatment data. We compared trends in numbers of active well pads between Core Areas and non-core areas (control) from 2009–2014 coinciding with SGEO implementation. We then compared trends in numbers of active well pads from 1986 through 2008 prior to SGEO policy and trends from 2009 through 2014 represented impacts post policy implementation.

We also utilized ANCOVA to evaluate differences in sage-grouse population trends between Core and non-core areas during an increasing population cycle (1996–2006) and a decreasing population cycle (2006–2013) both statewide and within MZs. As some leks occurred within relative close proximity to each other and count data were collected at essentially the same time each year on an annual basis, there was potential for spatial and temporal autocorrelation, respectively, among the data. We tested for temporal autocorrelation among sage-grouse count data using a Durbin-Watson test. If tests for autocorrelation were significant ($\alpha \leq 0.05$) we transformed the data using differencing to remove the temporal autocorrelation prior to employing the regressions within the ANCOVA (Box et al. 1994). Differencing is a technique that simply subtracts the previous year count from the current year count in sequence through the progression of years of data. By doing so, differencing removes the temporal trend but retains the mean across the data.

The ANCOVA procedure we employed used a suite of 4 models and systematically compared among models to determine the best fit for the comparison among the two trend lines (i.e., core and non-core) from linear regressions (Weisberg 1985). The models are as follows:

Model 1. $\hat{y} = b_{0,1}W_1 + b_{0,2}W_2 + b_{1,1}Z_1 + b_{1,2}Z_2$

Model 2. $\hat{y} = b_{0,1}W_1 + b_{0,2}W_2 + b_1X_1$

Model 3. $\hat{y} = b_0 + b_{1,1}Z_1 + b_{1,2}Z_2$

Model 4. $\hat{y} = b_0 + b_1X$

Where b_0 is the *y*-intercept, b_1 is the slope estimate, *W* is a label term, *Z* is the value associated with the corresponding *W*, and *X* is time. We first tested model 1 against model 2 to test the null hypothesis that the slopes of Core and non-core area sage-grouse trends were identical versus the alternate that they were different ($\alpha = 0.05$). If the null hypothesis was accepted, we then tested model 2 against model 4 to test the null hypothesis that the slopes were identical between core and non-core areas as well as the *y*-intercepts being identical between the two areas versus the alternate that the slopes were identical but the *y*-intercepts were different. In addition, if upon visual inspection of the plots of the compared slopes the y-intercepts were clearly distinct we first tested model 1 against model 3 to test the null hypothesis that the *y* - intercepts were identical between core and non-core areas versus the alternate that they were different. If the null hypothesis was accepted, we then tested model 3 against model 4 to test the null hypothesis that the *y*-intercepts were identical between Core and non-core areas as well as the slopes being identical between the two areas versus the alternate that the *y*-intercepts were identical but the slopes were different. We tested for normal probabilities and used Ordinary Least Squares assuming residuals were normally distributed. Model significance testing was accomplished using an *F*-test.

We calculated coefficients of variation (CV) for each year's average peak male lek attendance by MZ and statewide to obtain a measure of the variation around the mean of each year's lek attendance. We considered populations that exhibited smaller CVs to be more stable and resilient to changing environmental conditions (Harrison 1979).

Results

Well Pads

Well pads within statewide sage-grouse range increased from 1,946 in Core Area and 15,304 in non-core area in 1986 to 3,112 and 57,970, respectively, in 2014 (Table 1). Similarly, well pads in MZ I increased from 866 in Core and 8,244 in non-core in 1986 to 1,174 in Core and 34,178 in non-core in 2014 (Table 1). During this same time frame, well pads in MZ II increased from 1,080 in core and 7,060 in non-core to 1,938 in core and 23,792 in non-core in 2014. Comparing non-core to Core Area at the statewide scale, well pads increased at a ratio of 29 to 1 per year, 48 to 1 in MZ I, and 15 to 1 in MZ II (Table 1).

Core Area vs. Non-core Population Areas.—Rate of increase in active well pads differed ($F_{1,8}$ = 97.77, p < 0.01, r^2 = 1.00; Fig. 3a) as Core ($\hat{\beta}_1$ = 37.43, SE = 75.59, DF_{error} = 8, p = 0.63) was less compared to non-core ($\hat{\beta}_1$ = 1094.51, SE = 75.59, DF_{error} = 8, p < 0.01) areas at the statewide level. Within MZ I, rate of increase of well pads differed ($F_{1,8}$ = 95.16, p < 0.01, r^2 = 1.00; Fig. 3b) as Core ($\hat{\beta}_1$ = 16.46, SE = 54.56, DF_{error} = 8, p = 0.77) was less than in non-core areas ($\hat{\beta}_1$ = 769.2, SE = 54.56, DF_{error} = 8, p < 0.01). Rate of increase in active well pads differed ($F_{1,8}$ = 99.13, p < 0.01, r^2 = 1.00;Fig. 3c) in MZ II as Core ($\hat{\beta}_1$ = 20.97, SE = 21.61, DF_{error} = 8, p = 0.36) was lower compared to non-core ($\hat{\beta}_1$ = 325.31, SE = 21.61, DF_{error} = 8, p < 0.01) sage-grouse population areas.

Before (1986–2008)-After (2009–2014) Impact.—Trends in the rate of increase of number of active well pads were the same ($F_{1,25}$ = 0.11, p = 0.75, r^2 = 1.00) within Core Area before (1986–2008; $\hat{\beta}_1$ = 40.42, SE = 1.20, DF_{error} = 25, p < 0.01) and after (2009–2014; $\hat{\beta}_1$ = 37.42, SE = 9.13, DF_{error} = 25, p < 0.01; Fig. 4a) Core Area designation at the statewide level. In MZ I, the rate of increase in the number of active well pads differed ($F_{1,25}$ = 6.8, p < 0.02, r^2 = 1.00) as the rate before ($\hat{\beta}_1$ = 8.59, SE = 0.39, DF_{error} = 25, p = 0.01) was less than after ($\hat{\beta}_1$ = 16.45, SE = 2.99, DF_{error} = 25, p < 0.01) Core Area designation (Fig. 4b). In MZ II, the rate of increase in the number of active well pads in Core Areas was similar ($F_{1,25}$ = 2.09, p = 0.16, r^2 = 1.00) before ($\hat{\beta}_1$ = 31.83, SE = 0.98, DF_{error} = 251, p = 0.0) and after ($\hat{\beta}_1$ = 20.97, SE = 7.44, DF_{error} = 25, p < 0.01) SGEO implementation (Fig. 4c).

Male Sage-grouse Lek Attendance

We identified 958 active leks (674 Core Area leks and 284 non-core leks) statewide that were consistently surveyed each year from 1996 through 2014. Surveyed leks in MZ I and II included 63 and 611 in Core Areas and 110 and 174 in non-core areas, respectively. Lek counts increased from 1996 through 2006 and decreased from 2006 through 2013 (Table 2).

Male lek attendance for Core Area grouse populations exhibited smaller CVs as compared to non-core CVs (Table 3). Specifically, both MZ II and statewide CVs were consistently lower in Core than in non-core population areas across years. For MZ I, CVs were also lower in Core than in non-core population areas except in 1998 and 2004, when they were higher in Core. In addition, CVs in MZ II Core Area were lower than CVs in MZ I Core Area in 16 out of 18 years (Table 3).

Period of increase (1996–2006).—During the 1996–2006 population increase, average lek size (males per lek) in Core Areas was 14.9 (range: 5.2–31.0) statewide, 9.5 (range: 2.9–21.7) in MZ I, and 15.4 (range: 5.4–32.0) in MZ II (Table 4). Non-core lek averages during 1996–2006 were 6.4 (range: 2.8–9.7) statewide, 3.4 (range: 1.4–6.0) in MZ I, and 8.3 (range: 3.6–12.8) in MZ II (Table 4). Our 1996–2006 ANCOVA models considered an average of 10,259 (range: 3,516–20,893) peak male sage-grouse in Core Areas and 1,817 (range: 784–2,763) peak males in non-core areas at the statewide scale (Table 2). Our ANCOVA models also considered an average of 597 (range: 204–1,364) peak male sage-grouse in Core Areas and 369 (range: 150–658) in non-core areas in MZ I and 9,429 (range: 3,312–19,529) and 1,448 (range: 634–2,225) males in Core and non-core areas, respectively in MZ II (Table 2).

Our test for autocorrelation confirmed sage-grouse count data were temporally correlated ($p < 0.001$) so we transformed these data using the differencing technique and utilized the transformed count data (BIRDTRANS) for analysis. Differencing sacrifices the first year of data (1996) so transformed analyses began with 1997. Trends in BIRDTRANS differed ($F_{1,17}$ = 5.29, p = 0.034, r^2 = 0.27) as the rate in Core ($\hat{\beta}_1$ = 284.06, SE = 146.68, DF_{error} = 17, p = 0.07) was greater than non-core ($\hat{\beta}_1$ = 0.58, SE = 146.68, DF_{error} = 17, p = 0.99) population areas during 1997–2006 at the statewide scale (Fig. 5a). In MZ I, trends in BIRDTRANS were not different ($F_{1,17}$ = 0.46, p = 0.37, r^2 = 0.18) between Core ($\hat{\beta}_1$ = -0.06, SE = 26.47, DF_{error} = 18, p = 0.99) and non-core ($\hat{\beta}_1$ = 24.92, SE = 24.47, DF_{error} = 18, p = 0.36) population areas during 1997–2006 (Fig. 5b). In MZ II, trends in BIRDTRANS differed ($F_{1,17}$ = 6.04, p = 0.03, r^2 = 0.30) as the rate in Core ($\hat{\beta}_1$ = 263.79, SE = 129.68, DF_{error} = 17, p = 0.06) was greater than non-core ($\hat{\beta}_1$ = -4.01, SE = 129.68, DF_{error} = 17, p = 0.98) areas during 1997–2006 (Fig. 5c).

Period of decrease (2006–2013).—During the 2006–2013 population decrease, average lek size in Core Area was 19.3 (range: 9.7-31.0) statewide, 11.3 (range: 4.5–21.7) in MZ I, and 19.6 (range: 10.2–32.0) in MZ II (Table 4). Non-core lek size during 2007–2013 averaged 6.8 (range: 4.5–9.7) statewide, 3.3 (range: 1.4–5.5) in MZ I, and 9.0 (range: 6.1–12.5) in MZ II (Table 4).

Our ANCOVA models during 2006–2013 at the statewide scale considered average peak males in Core Area of 12,661 (range: 6,526–20,893), and 1,936 (range: 1,275–2,763) in non-core areas (Table 2). Peak males considered in MZ I averaged 710 (283–1,363) and 362 (range: 148–608) in Core and non-core areas, respectively. Peak males considered in MZ II averaged 11,952 (range: 6,243–19,529) and 1,574 (range: 1,065–2,175) in Core and non-core population areas, respectively (Table 2).

Trends in BIRDTRANS were not different ($F_{1,12}$ = 3.42, p = 0.09, r^2 = 0.23) between statewide Core ($\hat{\beta}_1$ = -245.13, SE = 178.64, DF_{error} = 13, p = 0.19) and non-core ($\hat{\beta}_1$ = -27.95, SE = 178.64, DF_{error} = 12, p = 0.88) population areas during 2006–2013 (Fig. 6a). In MZ I, trends in differenced transformed counts did not differ ($F_{1,12}$ = 0.02, p = 0.89, r^2 = 0.33) between Core ($\hat{\beta}_1$ = -11.15, SE = 15.07, DF_{error} = 12, p = 0.62) and non-core ($\hat{\beta}_1$ = -6.74, SE = 15.07, DF_{error} = 12, p = 0.77) population areas. In MZ II, trends in BIRDTRANS also were not different ($F_{1,13}$ = 3.54, p = 0.08, r^2 = 0.24) between Core ($\hat{\beta}_1$ = -230.69, SE = 168.43, DF_{error} = 13, p = 0.19) and non-core ($\hat{\beta}_1$ = 31.41, SE = 168.43, DF_{error} = 13, p = 0.85) population areas during 2006–2013 (Fig. 6c).

Policy Application

We found from 2012 through 2014, the average level of surface disturbance incurred from projects ranged from 0.7% to 18.7% per analysis area within a Core Area (Table 5). Project densities averaged 0.0 per 2.6 m^2 (640 ac) to 1.65 per 2.6 km^2. During this period, 174 projects occurred in Core Area with 126 (72.4%) initially conforming to SGEO stipulations. The remaining 27.6% of projects went through further review and mitigation practices including co-location on previously disturbed sites, site specific avoidance of sage-grouse habitat, habitat restoration and reclamation projects, and creation of habitat management plans to minimize disturbance and provide consistency with the SGEO (WGFD 2014). There were 26 (15%) instances where disturbances exceeded the 5% threshold. These exceedances were resultant of landscapes that included existing permit rights prior to 2008 (WGFD 2014). Such existing rights are recognized in the SGEO and are not subject to thresholds but are considered disturbance in some situations whether developed or not (State of Wyoming 2011).

Discussion

An important aspect of implementing natural resource policy is determining whether the policy is effective in achieving the desired outcome. In the case of Wyoming's SGEO, Core Areas as identified in the policy were intended to provide for the maintenance or increase of sage-grouse populations across the state (State of Wyoming 2008, 2011). We predicted a lesser rate of development within sage-grouse Core Area compared to non-core areas. Well pads did increase at a lesser rate statewide and in MZ's I and II post SGEO implementation (2009–2014) in Core Area as compared to non-core areas. This finding was not surprising as well pad development has historically been higher in non-core areas. In addition, during the mapping of Core Area, locations of existing development influenced placement of Core Area boundaries as policy makers constrained Core Area boundaries to avoid heavily developed areas and protect undeveloped areas (B. Budd, Wyoming SGIT, personal communication). Nonetheless, our analysis showed well pads in non-core area continued to increase at a higher rate than in Core Area. Although not definitive, these findings suggest the implementation of the Core Area policy pertaining to oil and gas development was being met during the timeframe we analyzed.

Our before-after SGEO policy comparisons provide further evidence of the role Core Area plays within the SGEO policy in relation to development statewide and in MZ II. In both instances, the rate of development remained the same throughout 1986–2014. Thus, the SGEO may have been influential at maintaining the slow pace of development that has historically occurred in areas now designated as Core Area. Alternatively, the slow development pace may simply be the result of continued low interest in resource development within these areas mapped as Core Area. Interestingly, we did not find this in MZ I. Rather, the rate of development in Core Areas in MZ I actually was higher post SGEO implementation compared to long-term development. This trend began around the early 2000s. We suspect this trend may be at least in part due to coal-bed methane gas development (Stilwell et al. 2012) and the more recent interest in oil production maintaining well pad development in the area as evidenced by an increase in WOGCC permits since a low in 2009 (Applegate and Owens 2014).

We predicted male sage-grouse lek attendance would be higher in Core Areas before and after implementation of the SGEO. We found mixed results in male lek attendance, depending on the scale and timeframe. Total male sage-grouse lek attendance was greater in Core Area compared to non-core area at the statewide scale and in MZ II, but not in MZ I, during 1996–2006, when sage-grouse populations in Wyoming were notably increasing. Trends in male sage-grouse lek attendance did not differ between Core and non-core population areas statewide, in MZ I, or MZ II during 2006–2013, when sage-grouse were declining across Wyoming.

When conditions are favorable, sage-grouse populations can increase after a period of decrease (Garton et al. 2011). During the 1996 through 2006 recent peak, our data, in agreement with Fedy and Aldridge (2012), demonstrated Wyoming sage-grouse populations increased dramatically both in Core and non-core areas statewide and in MZ II. And, within these area designations, we found increases within Core Area were significantly higher than those observed in non-core area. We also found population variation was less in MZ II Core than in non-core areas indicating stability and resilience within Core Area sage-grouse populations in this management zone. Populations exhibiting higher variability may be more prone to significant decline as opposed to those with lower variability (Pimm 1991, Vucetich et al. 2000). Thus, in Core Area in MZ II, it appears that trends in sage-grouse populations here were able to remain more consistent due to slow rate of energy development likely combined with favorable habitats. Comparatively, in MZ I, while total male lek attendance also increased during population increase, increases in Core did not out pace those in non-core. Conditions within Core Area in MZ I, may not be more favorable to sage-grouse populations than those in non-core areas or certainly not to the degree found in MZ II. This result may be due a combination of factors including degree of development, habitat condition, or relative lower population levels.

Regardless of timeframe, we found no statistical differences between total male lek attendance in Core and non-core populations in MZ I. However, CVs indicated population numbers were more stable in Core Area versus non-core for most years (Harrison 1979). Regardless, MZ I habitats have been described as being less favorable to sage-grouse, in general, as MZ I includes the interface of sagebrush with the Great Plains (Knight et al. 2014) resulting in patchier sagebrush habitats across only 14% of the area compared to 45% in MZ II (Knick 2011). In addition, the region encompassed in MZI has experienced historical land treatments aimed at reducing or removing sagebrush, further exacerbating the fragmentation of naturally occurring vegetation (BLM 2010). From a development perspective, MZ I experienced tremendous growth from natural gas development (primarily coal bed methane) during the 1990s through the early 2000s (Stilwell et al. 2012) and our well pad data reflect this. One study conducted in MZ I found that by 2005, male lek attendance within coalbed methane fields was 46% less than at leks outside of these areas (Walker et al. 2007). Doherty et al. (2008) also found sage-grouse were 1.3 times more likely to occupy winter habitats that had not been developed for energy. They found a density of well spacing at12.3 well pads per 4 km^2 resulted in a decrease in odds of sage-grouse use by 0.30 compared to the average landscape (odds 0.57 vs. 0.87) in MZ I. In addition, lower numbers of males attending leks in MZ I compared to MZ II suggest MZ I leks have difficulty in recovering from energy development impacts, which occur immediately (1 year) after development in MZ I (Gregory and Beck 2014). Disease also likely contributed negatively to sage-grouse populations in MZ I. For example, Taylor et al. (2013) found after West Nile virus outbreaks in 2003 and 2007, lek inactivity rates in MZ I doubled. All of these factors likely contributed to Core Area performance not exceeding non-core in MZ I.

The majority of project development from 2012–2014 within Core Area fell within the thresholds of the SGEO. Yet, over one quarter of the projects did not initially meet all of the threshold requirements. It is our understanding the impacts associated with these remaining projects were minimized through further guidance with the WGFD and land management agencies (WGFD 2014). An unquantifiable aspect of the SGEO is the effort and practice of agencies applying the components of the SGEO across the Core Areas.

Conclusion

While difficult to ascertain the effects of the policy so soon after implementation, it appears Core Area designations combine reasonable habitats with low paced levels of oil and gas development, which contribute to conserving sage-grouse. We suggest these areas have contributed to the sustainability of sage-grouse populations at the statewide level and within MZ II enabling sage-grouse to continue to fluctuate and exhibit population cycles. However, despite implementation of the SGEO, we are concerned with the relatively poorer performance of sage-grouse populations in MZ I. Garton et al. (2011) developed a predictive model suggesting continued declines in MZ I potentially leading to extinction in 2107 if projected trends continue. Perhaps the current slowdown in natural gas development and increased use of horizontal drilling, which places multiple wells per pad (Applegate and Owens 2014), concurrently reducing numbers of well pads, combined with increased reclamation, restoration, and protection of habitats through easement (Copeland et al. 2013) may help provide conditions for birds to respond more favorably. In addition, a recent study reported nesting success in MZ I was higher in areas with fewer reservoirs and higher sagebrush cover, suggesting two critical issues to focus energy development mitigation in this management zone to benefit sage-grouse (Kirol et al. 2015*b*). Success may ultimately rest on whether the state of Wyoming maintains the political fortitude to keep this experiment in sage-grouse conservation operating into the future.

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Table 1. Numbers of well pads by year statewide and within WAFWA MZ I and MZ II in Wyoming, USA, 1986–2014.

Year	Number of Active Well Pads					
	Statewide		MZ I		MZ II	
	Core	Non-core	Core	Non-core	Core	Non-core
1986	1946	15304	866	8244	1080	7060
1987	1958	15538	870	8386	1088	7152
1988	2000	15878	880	8562	1120	7316
1989	2052	16128	904	8646	1148	7482
1990	2102	16498	922	8746	1180	7752
1991	2152	16900	938	8874	1214	8026
1992	2178	17270	946	8988	1232	8282
1993	2194	17952	950	9096	1244	8856
1994	2228	18664	956	9258	1272	9406
1995	2266	19508	958	9428	1308	10080
1996	2300	19918	966	9494	1334	10424
1997	2324	20614	970	9688	1354	10926

1998	2364	21510	974	9968	1390	11542
1999	2386	22588	976	10406	1410	12182
2000	2420	24234	980	11446	1440	12788
2001	2466	26366	994	12772	1472	13594
2002	2510	28656	1002	14096	1508	14560
2003	2550	30500	1004	15234	1546	15266
2004	2622	33158	1016	16936	1606	16222
2005	2708	37142	1032	19822	1676	17320
2006	2774	41490	1056	23074	1718	18416
2007	2836	45846	1074	26134	1762	19712
2008	2878	49624	1086	28590	1792	21034
2009	2940	52514	1096	30352	1844	22162
2010	2964	53944	1102	31316	1862	22628
2011	3014	55614	1120	32558	1894	23056
2012	3050	56646	1132	33240	1918	23406
2013	3102	57276	1160	33686	1942	23590
2014	3112	57970	1174	34178	1938	23792

Table 2. Peak male sage-grouse counted from annual lek counts statewide and within WAFWA management zones (MZ I and MZ II) based on 958 active leks in Wyoming, USA with consistent lek counts, 1996–2013.

Year	Peak Total Male Sage-grouse Counted					
	Statewide		MZ I		MZ II	
	Core	Non-core	Core	Non-core	Core	Non-core
Period of Increase						
1996	3516	784	204	150	3312	634
1997	4103	1096	185	212	3918	884
1998	6384	1386	288	335	6096	1051
1999	9127	1861	558	288	8569	1573
2000	11068	2475	842	658	10226	1817
2001	9021	1976	520	497	8501	1479
2002	8062	1639	367	248	7695	1391
2003	9709	1765	555	320	9154	1445
2004	10715	1518	508	265	10207	1253
2005	17686	2728	1177	503	16509	2225
2006	20893	2763	1364	588	19529	2175
Period of Decrease						

2006	20893	2763	1364	588	19529	2175
2007	18544	2496	1137	608	17407	1888
2008	14613	2379	853	473	13760	1906
2009	13444	1993	550	367	12894	1626
2010	10966	1761	647	297	10319	1464
2011	8621	1275	463	210	8158	1065
2012	7684	1299	379	204	7305	1095
2013	6526	1520	283	148	6243	1372

Table 3. Coefficients of variation for core and non-core peak male populations in WAFWA MZ I, MZ II, and Statewide in Wyoming, USA, 1997–2014.

Year	Coefficient of Variation					
	Statewide		MZ I		MZ II	
	Core	Non-core	Core	Non-core	Core	Non-core
Period of Increase						
1997	219.3	272.6	252.7	321.6	214.9	243.5
1998	202.7	242.4	263.9	259.5	197.7	225.8
1999	173.5	233.2	183.0	301.5	171.7	199.9
2000	155.2	199.4	174.0	229.2	153.6	183.7
2001	162.1	206.7	164.3	212.8	160.3	194.7
2002	157.0	258.2	185.3	242.9	153.3	227.7
2003	145.4	211.7	199.4	241.0	141.4	186.9
2004	157.8	232.8	218.4	210.0	153.3	209.8
2005	152.4	226.8	175.4	229.1	150.2	204.1
2006	143.0	222.2	178.9	218.6	140.1	205.2
Period of Decrease						

2007	137.9	225.6	153.6	211.3	135.9	215.4
2008	156.8	227.6	162.0	219.7	155.0	208.4
2009	149.7	235.7	179.7	207.8	145.6	214.8
2010	142.7	218.3	168.3	278.5	140.1	188.5
2011	156.2	239.2	158.8	277.0	154.1	209.3
2012	163.0	238.8	154.5	263.9	160.7	208.7
2013	163.2	227.1	161.5	326.6	159.9	185.1
2014	170.3	232.5	143.9	361.4	167.6	189.1

Table 4. Average annual peak per lek attendance of male sage-grouse obtained from annual lek counts statewide and within WAFWA management zones (MZ I and MZ II) based on 958 active leks with consistent counts in Wyoming, USA, 1996–2013.

Year	Average Peak Male Sage-grouse per Lek					
	Statewide		MZ I		MZ II	
	Core	Non-core	Core	Non-core	Core	Non-core
Period of Increase						
1996	5.2	2.8	3.2	1.4	5.4	3.6
1997	6.1	3.9	2.9	1.9	6.4	5.1
1998	9.5	4.9	4.6	3.1	10.0	6.0
1999	13.5	6.6	8.9	2.6	14.0	9.0
2000	16.4	8.7	13.4	6.0	16.7	10.4
2001	13.4	7.0	8.3	4.5	13.9	8.5
2002	12.0	5.8	5.8	2.3	12.6	8.0
2003	14.4	6.2	8.8	2.9	15.0	8.3
2004	15.9	5.4	8.1	2.4	16.7	7.2
2005	26.2	9.6	18.7	4.6	27.0	12.8
2006	31.0	9.7	21.7	5.4	32.0	12.5
Period of Decrease						
2006	31.0	9.7	21.7	5.4	32.0	12.5
2007	27.5	8.8	18.1	5.5	28.5	10.9

2008	25.5	8.4	13.5	4.3	22.5	11.0
2009	20.0	7.0	8.7	3.3	21.1	9.3
2010	16.3	6.2	10.3	2.7	16.9	8.4
2011	12.8	4.5	7.4	1.9	13.4	6.1
2012	11.4	4.6	6.0	1.9	12.0	6.3
2013	9.7	5.4	4.5	1.4	10.2	7.9

Table 5. Average surface disturbance and density of projects within Wyoming's 31 Core Areas including Core Area size, % surface disturbance, and disturbance density (No./2.66 km^2), 2012–2014 (WGFD 2014).

Core Area	MZ	km^2	% Disturbance (range)		No./2.66 km^2 (range)	
Buffalo	I	1,974	4.1	(1.5-6.8)	0.2	(0.1-0.3)
Douglas	I	356	18.7	(4.1-42.9)	0.6	(0.3-0.8)
North Gillette	I	493	3.1	(2.4-3.9)	0.4	(0.1-0.7)
Newcastle	I	481	7.0	(2.5-10.2)	1.1	(0.6-1.3)
North Glenrock	I	556	11.2	(N/A)	0.8	(N/A)
North Laramie	I	890	4.3	(2.8-5. 8)	0.1	(0.0-0.1)
Thunder Basin	I	3,119	4.9	(0.9-25.7)	0.2	(0.1-1.0)
Natrona	I, II	10,011	5.3	(0.5-11.9)	0.2	(0.1-1.5)
Black's Fork	II	753	n/a		n/a	
Continental Divide	II	697	1.4	(1.3-1.6)	0.3	(0.3-0.3)
Crowheart	II	1,259	10.6	n/a	1.7	n/a

Daniel	II	2,069	1.9	(1.7-2.2)	0.0	(0.0-0.0)
Elk Basin East	II	144	No projects		No projects	
Elk Basin West	II	41	No projects		No projects	
Fontenelle	II	608	No Projects		No projects	
Grass Creek	II	660	No projects		No projects	
Greater South Pass	II	18,587	4.6	(0.2-53.4)	0.0	(0.0-2.1)
Hanna	II	2,958	5.6	(0.6-12.5)	0.1	(0.0-0.3)
Heart Mountain	II	487	No projects		No projects	
Hyattville	II	585	No projects		No projects	
Jackson	II	342	No projects		No projects	
Little	II	199	No		No	

Mountain			projects		projects	
Oregon Basin	II	2,462	11.5	(3.6-26.1)	0.2	(0.0-0.5)
Sage	II	2,566	1.2	(0.8-1.8)	0.0	(0.0-0.0)
Salt Wells	II	1,595	No projects		No projects	
Seedskadee	II	352	4.6	(2.1-9.3)	0.4	(0.1-0.7)
Shell	II	147	No projects		No projects	
South Rawlins	II	3,694	14.6	(0.4-31.4)	0.2	(0.0-1.3)
Thermopolis	II	105	No projects		No projects	
Uinta	II	950	5.5	(1.5-16.8)	0.1	(0.0-0.1)
Washakie	II	2,599	0.7	(0.6-0.9)	0.1	(0.0-0.1)

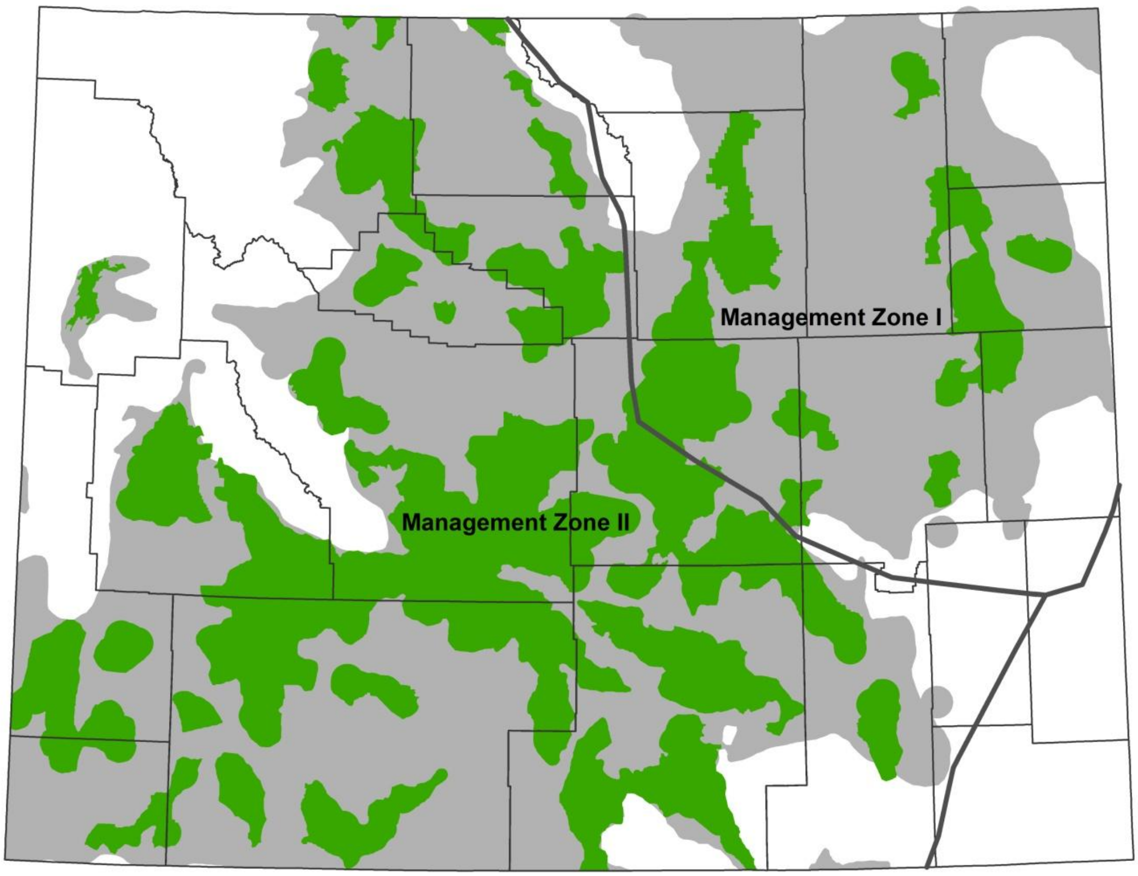

Fig. 1. Location map of 31 core population areas (green-shaded areas; gray-shaded areas represent sage-grouse range where non-core sage-grouse populations occur) within current sage-grouse range and WAFWA Management Zones I and II in Wyoming, USA.

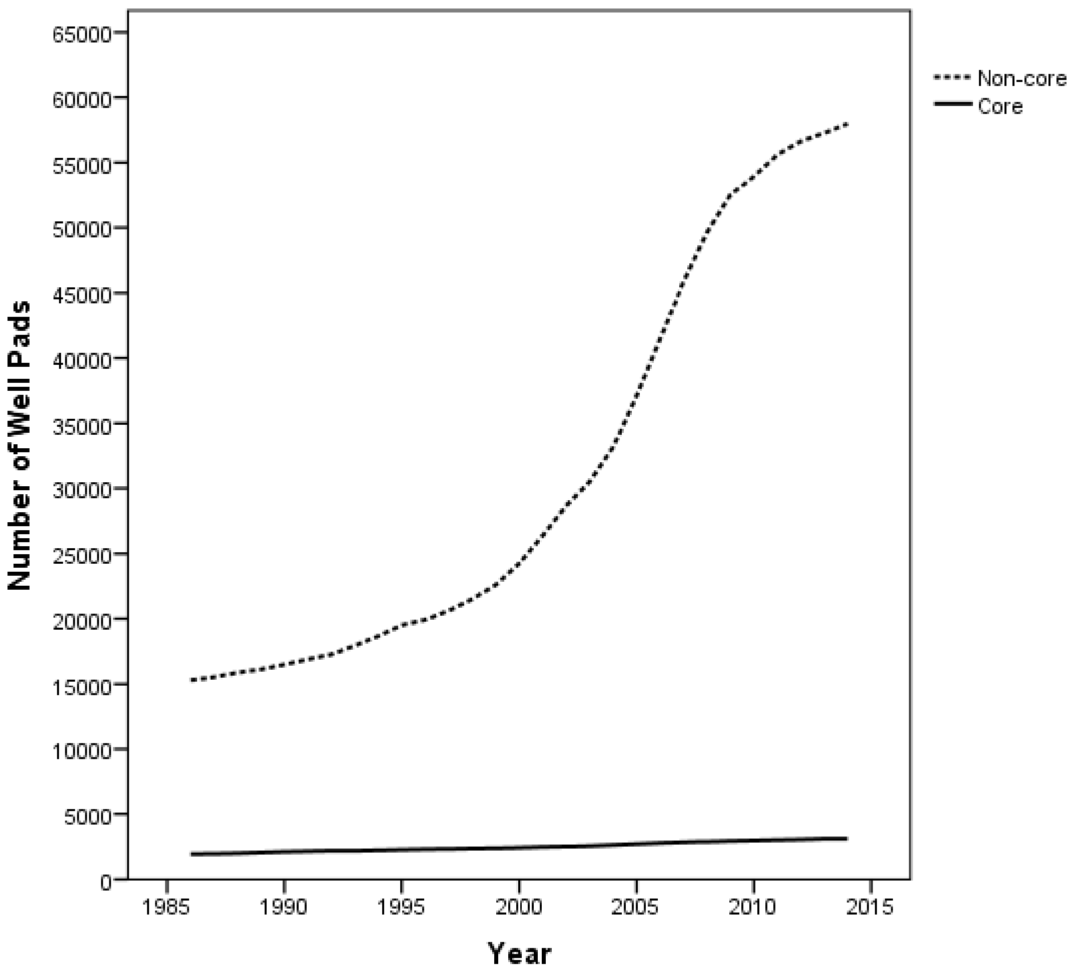

Fig. 2. Number of well pads in Core and non-core areas from 1986–2014, Wyoming, USA.

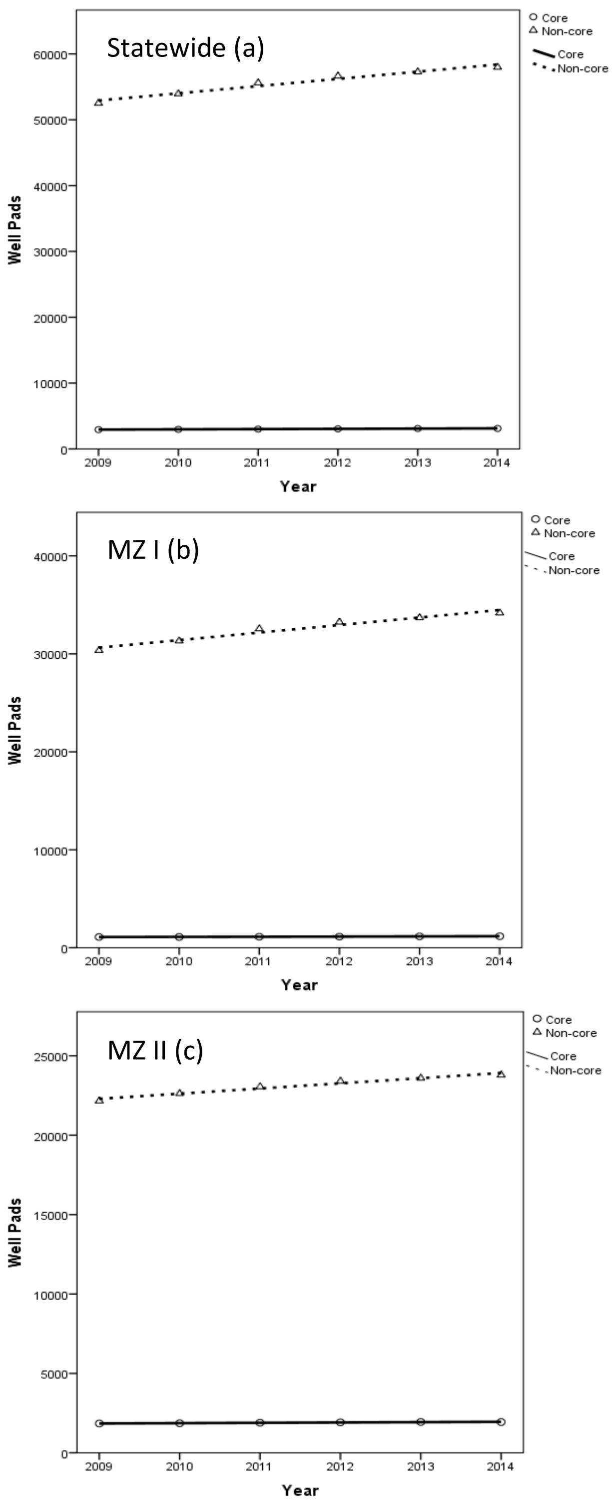

Fig. 3. Well pad comparison between core and non-core areas in Wyoming, USA, 2009–2014. Data are reported at statewide (a) and management zone (MZ I [b] and MZ II [c]) scales.

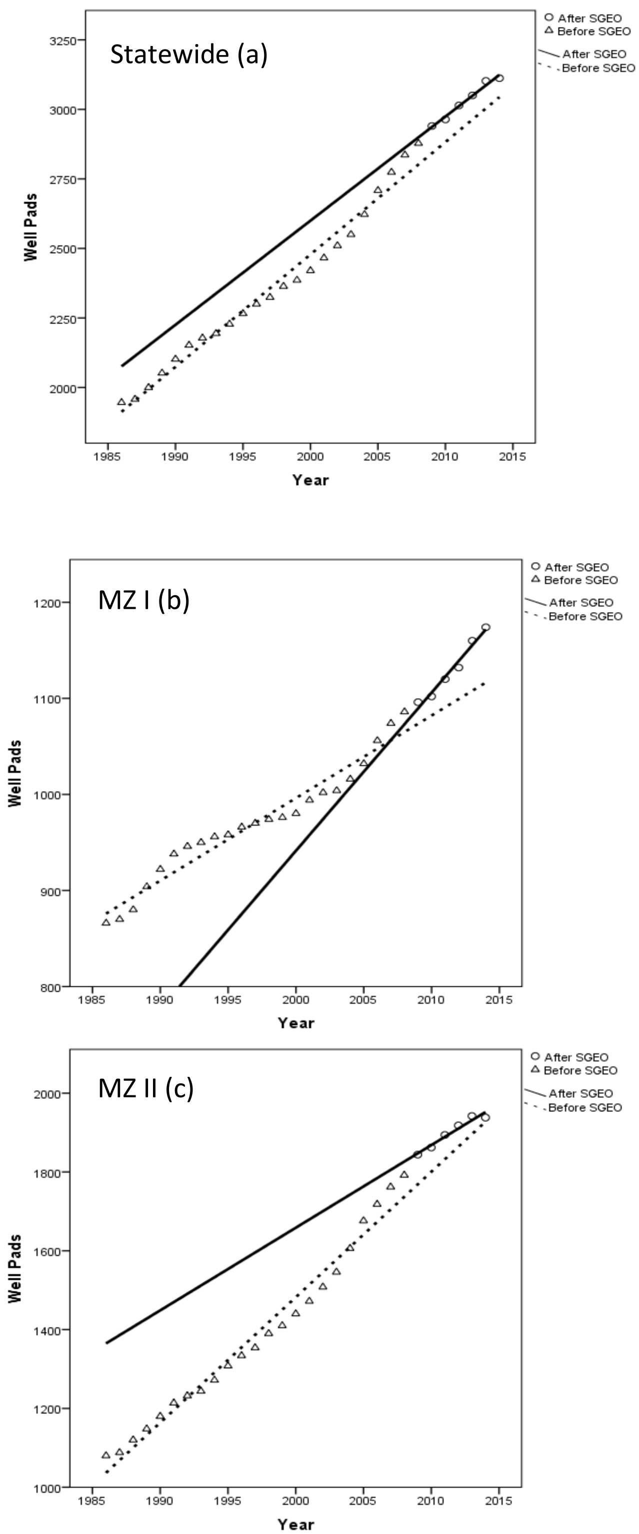

Fig. 4. Oil and gas well pad comparison between before (1986–2008) and after (2009–2014) SGEO implementation in Core Area in Wyoming, USA. Data are reported at statewide (a) and management zone (MZ I [a] and MZ II [b]) scales. Extended linear trend lines for after SGEO (2009–2014) are provided for slope comparisons.

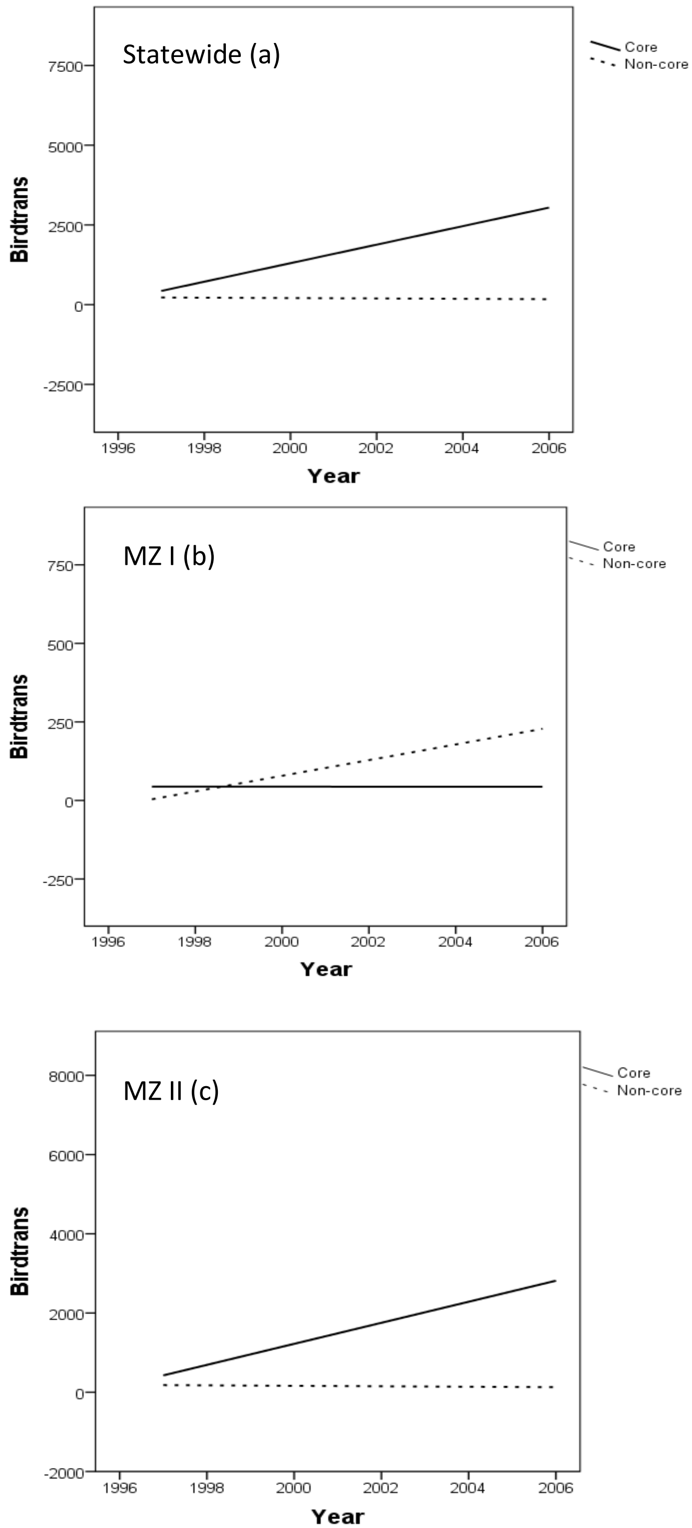

Fig. 5. Birdtrans (differenced peak male sage-grouse numbers) comparison between Core and non-core areas in Wyoming, USA during period of population increase (1997–2006; *note—differencing removed the year 1996*). Data are reported at statewide (a) and management zone (MZ I [b] and MZ II [c]) scales. Linear trend lines are provided for comparisons.

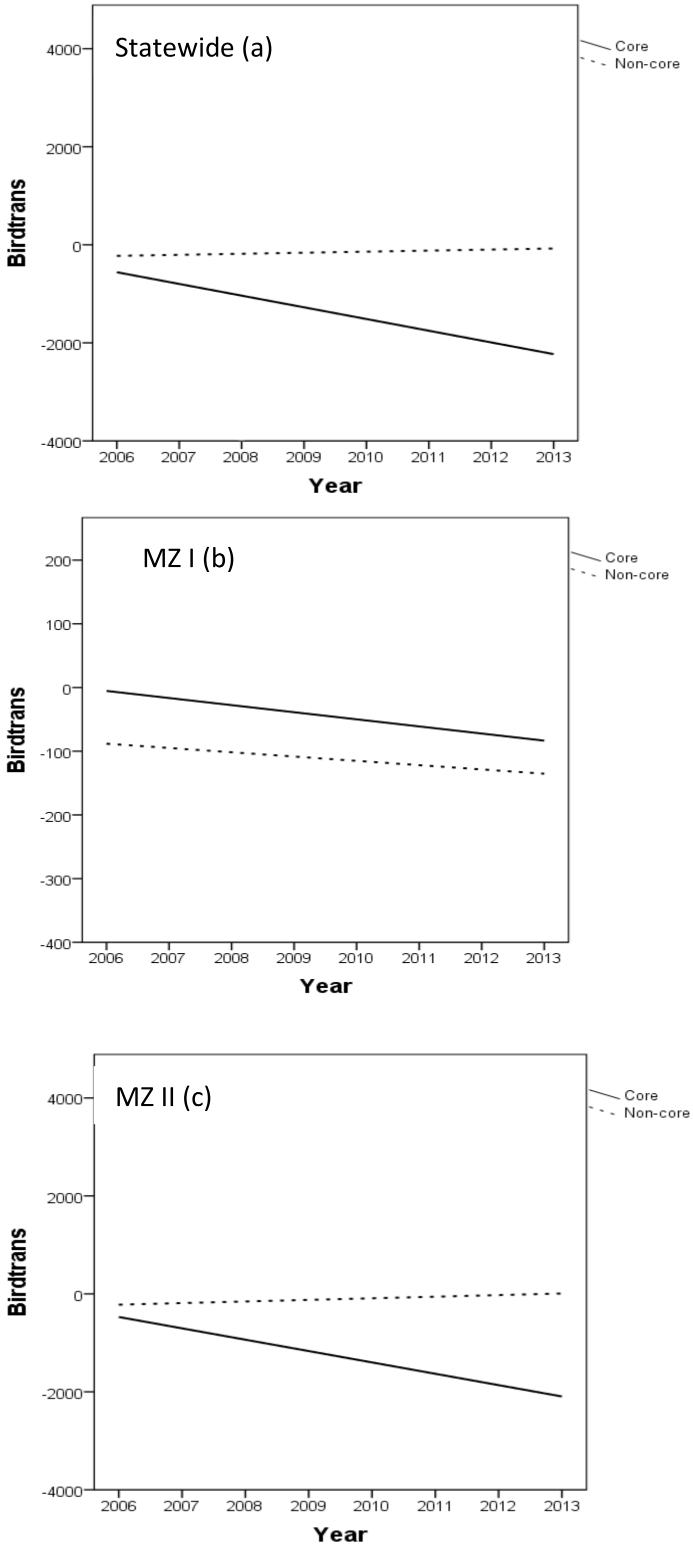

Fig. 6. Birdtrans (differenced peak male sage-grouse numbers) comparison between core and non-core areas in Wyoming, USA during period of population decrease (2006–2013; *note—differencing removed the year 2005*). Data are reported at statewide (a) and management zone (MZ I [b] and MZ II [c]) scales. Linear trend lines are provided for comparisons.

MULE DEER HABITAT PROTECTIONS AND POPULATION PRODUCTIVITY IN RESPONSE TO WYOMING'S SAGE-GROUSE CORE AREAS

R. Scott Gamo[a,], and Jeffrey L. Beck[b]*

[a] *Graduate Assistant, Department of Ecosystem Science and Management, University of Wyoming, Laramie, WY 82071, USA, and Staff Terrestrial Biologist, Wyoming Game and Fish Department, Cheyenne, WY 82006, USA*

[b] *Associate Professor, Department of Ecosystem Science and Management, University of Wyoming, Laramie, WY 82071, USA*

☆Research was supported by Wyoming Game and Fish Department.

*Correspondence: R. Scott Gamo, Wyoming Game and Fish Department, 5400 Bishop Blvd., Cheyenne, Wyoming 82006, USA.

E-mail: scott.gamo@wyo.gov; Phone-1+ 307-777-4509

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Abstract

Expanding anthropogenic impacts have been shown to negatively affect habitat use by many wildlife species including mule deer (*Odocoileus hemionus*). Recent policy has been implemented in western states to conserve habitat and populations of greater sage-grouse (*Centrocercus urophasianus*) including Wyoming's Sage-Grouse Core Area (SGEO) implemented in 2008. Core Areas, the lands designated for careful management within the Wyoming policy, have potential to provide protection for non-target species such as mule deer that share substantial habitat with sage-grouse. Objectives for our study focused on examining the influence of Core Area on mule deer in Wyoming including: 1) quantifying oil and gas development on mule deer crucial winter range and Hunt Areas in respect to Core Area overlap, and 2) using fawn:adult female (hereafter fawn:female) ratios, evaluate whether mule deer populations overlapping Core Areas received fitness benefits. We used oil and gas well data from the Wyoming Oil and Gas Conservation Commission and fawn:female ratios for mule deer Hunt Areas derived from Wyoming Game and Fish Department data. Within an ANCOVA modeling framework, we conducted our well pad evaluations across designated mule deer crucial winter ranges (1980–2013) and statewide mule deer Hunt Areas (1995–2013). Mule deer winter ranges overlapping Core Areas included fewer well pads and displayed less increasing trends in well pads than did winter ranges occurring in non-core areas during 1980–2013. Mule deer Hunt Areas overlapped by Core Area displayed less increasing trends of well pads as the percentage of Core Area overlap increased. The trend ($\hat{\beta}_1 = 0.00$) in fawn:female ratios (mean = 0.69, range: 0.55–0.83) was higher in hunt areas with $\geq$70% Core Area overlap compared to a slight but significant negative trend ($\hat{\beta}_1 = -0.005$) in fawn:female ratios (mean = 0.64, range: 0.53–0.73) in hunt areas with no Core Area overlap ($\leq$1%) from 1995–2013. Using one-sample *t*-tests, we evaluated Core Area influence on mule deer productivity comparing fawn:female ratios across multiple quantile overlaps of Hunt Areas with Core Area with a 0.66 fawn:female threshold indicative of an increasing population. Hunt Areas with Core Area overlap ≥70% exceeded 0.66 fawns:female. Evidence of protection provided by Core Areas to mule deer winter range habitat and the positive influence on fawn:female ratios provides additional support for the surrogate role of sage-grouse as an umbrella species for mule deer. The relative change in fawn:female ratios has significant implications to mule deer populations across time.

Keywords: *Centrocercus urophasianus*, fawn:female ratio, greater sage-grouse, mule deer, *Odocoileus hemionus*, oil and gas development, umbrella species, Wyoming Sage-Grouse Executive Order

Introduction

Conservation of ungulates is increasingly complex as their habitats continue to be subject to expanding human development from natural resource extraction, urbanization, industrial infrastructure, and agricultural expansion. For example, the global demand for energy is estimated to increase by 40% within the next 20 years accelerating oil, gas, coal, and renewable energy development (International Energy Agency 2015). Expanding energy development is projected to result in >200,000 km^2 of land utilized by various forms of energy development in the United States by 2035 (McDonald et al., 2009). Impacts from anthropogenic expansion can negatively affect ungulate use of winter ranges (Sawyer et al., 2006; Beckman et al., 2012, Buchanan et al., 2014), migration routes (Sawyer et al,. 2009a; Lendrum et al,. 2013; Sawyer et al., 2013), and other seasonal habitats (Buchanan et al., 2014; Blum et al., 2015). Mule deer (*Odocoileus hemionus*) avoided oil and gas development infrastructure in the upper Green River Basin of western Wyoming as development increased through time on important winter ranges selecting habitats $\geq$3 km from active fields (Sawyer et al., 2006). Timing of mule deer migration was influenced by anthropogenic disturbance in northwestern Colorado as mule deer hastened their travel through higher (well pads · 0.19 km^{-2}) developed areas as compared to lesser (well pads · <0.01 km^{-2}) developed areas (Lendrum et al., 2013). Mule deer avoided oil and gas infrastructure out to 600–800 m in a study evaluating mule deer use of shale oil and gas development in northwestern Colorado (Northrup et al,. 2015). Mule deer avoided areas of higher disturbance areas within mine complexes spending more time within less disturbed areas in southwestern Idaho (Blum et al., 2015). Similar avoidance of human activity has been observed with other ungulate species including elk (*Cervus elaphus*; Kuck et al, 1985; Buchanan et al,. 2014), pronghorn (*Antilocapra americana*; Beckman et al., 2012), and caribou (*Rangifer tarandus* ssp.; Cameron et al., 2005; Sorensen et al,. 2007; Polfus et al., 2011) that inhabit areas with mining, oil and gas development, or other human associated infrastructure. Avoidance of human infrastructure by ungulates can lead compromised fitness rates including survival due to use of less desirable habitat leading to increased energetic costs (Parker and Robbins, 1984; Parker and Gillingham, 1990; Rumble et al,. 2005), impacts to parturition and recruitment (Cook et al,. 2004; Tollefson et al., 2011), increased winter mortality (Parker et al., 2005), and increased potential for direct mortality (vehicle collisions) and predation (Vors et al., 2006).

In response to these impacts, state wildlife management agencies such as Wyoming Game and Fish Department (WGFD), have developed protective stipulations to help minimize the impacts of development on mule deer (WGFD 2009). Stipulations include recommendations of no human activity within crucial mule deer winter range from 15 November–30 April. However, these stipulations are only recommendations—they are not a rule of law or enforceable policy, and may or may not be implemented by land management agencies. Many western states have implemented conservation policies to protect greater sage-grouse (*Centrocercus urophasianus*; hereafter, sage-grouse) and their habitats at a landscape level to assist in preventing a potential listing for sage-grouse as a threatened or endangered species (State of Wyoming 2008; Stiver, 2011; State of Wyoming 2011; State of Idaho 2012; State of Montana 2014; State of Nevada 2014; State of Oregon 2015). Wyoming was the first state to implement protective policy through its Sage-grouse Executive Order ([SGEO] State of Wyoming 2008). The SGEO is a natural resource policy designed to maintain or improve sage-grouse populations and habitat in Wyoming by minimizing density and size of anthropogenic disturbances in designated sage-grouse Core Areas (State of Wyoming 2008, 2011). The Core Areas were delineated through mapping of historically high density sage-grouse leks (Doherty et al., 2010) combined with limited human development (State of Wyoming 2008). The SGEO management strategy constrains energy development and other surface disturbing activities across approximately 24% of Wyoming. As a regulatory mechanism, the SGEO, as applied within Core Areas may provide protections to mule deer more effectively than specific mule deer seasonal range stipulations.

Presumably, greater limits placed on development and other anthropogenic activities in landscapes encompassed by Core Area in Wyoming should yield benefits to large, mobile species such as mule deer. The SGEO prescribes disturbance density levels that should not exceed $1 \cdot 2.6\ km^{-2}$ ($1 \cdot 640\ ac^{-1}$) within a defined analysis area (e.g., Holloran, 2005; Doherty, 2008) and total surface disturbance acreage should not exceed 5% of the analysis area (State of Wyoming 2011). Mule deer may respond favorably to practices that minimize development and result in less fragmentation and disturbance from human activity. Reducing disturbance activity through the piping of oil and gas fluids rather than completely relying on truck transport may mitigate development impacts to mule deer (Sawyer et al., 2009b) and, in effect, improve habitat use. The effect of improved habitat use on mule deer may be reflected in population parameters such as higher pregnancy rates, increases in fawn:adult female (number of fawns per 1 adult female; hereafter, fawn:female) ratios, higher adult winter survival, and ultimately increasing populations (Tollefson et al., 2010; Bergman et al., 2014). Fawn:female ratios are a common metric used by wildlife agencies to assess productivity of deer herd units (Rabe et al., 2002; Skalski et al., 2005). Such data have been collected and recorded in Wyoming by the WGFD since the 1960's (WGFD Job Completion Reports; WGFD, unpublished data). Some have advocated creative solutions such as utilizing policy driven land protections for conserving ungulates and their habitats (Copeland et al., 2014). Sage-grouse Core Area is part of a policy driven land protection mechanism and may protect important seasonal habitats for mule deer, the benefits of which may be reflected in a population response.

The purpose of our study was to evaluate whether sage-grouse Core Area provides benefits to seasonally important mule deer habitat and populations in Wyoming. Secondarily, we examined evidence to ascertain whether sage-grouse may function as an umbrella species for mule deer. Our objectives included: 1) quantifying oil and gas development in both mule deer crucial winter range and WGFD Hunt Areas in respect to Core Area overlap, and 2) using fawn:female ratios , evaluate whether mule deer populations overlapping Core Areas received fitness benefits. We first predicted that mule deer crucial winter range and WGFD Hunt Areas occurring within Core Areas would have less anthropogenic disturbance than crucial winter ranges or Hunt Areas outside of Core Area, respectively. Second, we predicted that mule deer populations using Hunt Areas overlapped by Core Area would display higher productivity as measured by fawn:female ratios than mule deer populations that utilized areas outside of Core

Area. If data support both predictions they provide evidence that greater sage-grouse may serve as an umbrella species for mule deer.

Methods

Study Area

Our study area included occupied mule deer range across Wyoming, USA. Specifically, we focused on WGFD designated crucial winter ranges within current occupied sage-grouse range (Figure 1) and statewide WGFD mule deer population Hunt Areas (Fig. 2). Winter ranges are populated by mule deer during winter months (Garrot et al., 1987; Brown, 1992) where WGFD prescribes seasonal stipulations of no human activity from 15 November through 30 April on designated crucial winter ranges (WGFD 2009). Typically, crucial winter ranges consist of areas that provide western or southern exposure, windswept landscapes, and support sagebrush (*Artemisia* L. spp.)/antelope bitterbrush (*Purshia tridentata* [Pursh] DC.) vegetative complexes, or combinations of these characteristics.

One-hundred-forty mule deer Hunt Areas ranging in size from 98 to 13,661 km^2 (mean = 1,852 km^2) occur across Wyoming and are delineated to encompass subpopulations of mule deer within larger herd management units. Hunt Areas include mule deer habitats overlapped by sage-grouse Core Areas within the sagebrush-dominated basins in the western, central, and northeastern portions of the state and often coincide with energy development. The Wyoming Basins area occurs within the western half of the state and consists of multiple basins between mountain ranges (Rowland and Leu, 2011). Major basins include the Bighorn, Great Divide, Green River, and Shirley. Wyoming Basins are considered a stronghold for sage-grouse because range-wide they contain the second largest area of sage-grouse habitat (Wisdom et al., 2011) and the largest populations (Doherty et al., 2015). Northeastern Wyoming rangelands, include the

Powder River Basin where sage-grouse populations are not as robust as in the Wyoming Basins (Garton et al., 2011; Doherty et al., 2015; WAFWA 2015). Wyoming Basins vegetation consists typically of shrub steppe dominated by Wyoming big sagebrush (*A. t.* Nutt. subsp. *wyomingensis* Beetle & Young) and mountain big sagebrush (*A. t.* Nutt. subsp. *vaseyana* [Rydb.] Beetle), but also include areas of black (*A. nova* A. Nelson) and low sagebrush (*A. arbuscula* Nutt.) whereas northeast Wyoming contains comparatively less sagebrush and more grass coverage (Rowland and Leu, 2011; Knight et al., 2014). Common grasses in the Wyoming Basins and northeast Wyoming include bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh] Á. Löve), needle and thread (*Hesperostipa comata* [Trin. & Rupr.] Barkworth), western wheatgrass (*Pascopyrum smithii* [Rydb.] Á. Löve), and a variety of blue grasses (*Poa* L. spp.) Forbs vary in abundance depending on precipitation and soil characteristics. Invasive grass species such as cheatgrass (*Bromus tectorum* L.) are common in northeastern Wyoming and are becoming more common in the Wyoming Basins. Rocky Mountain juniper (*Juniperus scopulorum* Sarg.) and ponderosa pine (*Pinus ponderosa* Lawson & C. Lawson) occur on rocky uplifts and in river drainages.

Hunt Areas lying entirely within mountain ranges in Wyoming typically do not overlap with energy development. However, Hunt Areas overlapping mountain ranges with adjacent foothills and rangelands typically include some level of energy or extractive resource development. Wyoming mountain ranges encompass temperate forests with tree species at lower elevations including lodgepole (*Pinus contorta* Douglas ex Loudon) and ponderosa pines (*P. ponderosa* Lawson & C. Lawson), and quaking aspen (*Populus tremuloides* Michx.). Douglas fir (*Pseudotsuga menziesii* [Mirb.] Franco) and Englemann spruce (*Picea engelmannii* Parry ex Engelm.) form forests at higher elevations. The shortgrass prairie in the southeast corner of the state is composed of grasses including blue grama (*Bouteloua gracilis* [Willd. ex Kunth] Lag. ex Griffiths), buffalo grass (*B. dactyloides* [Nutt.] J.T. Columbus), western wheatgrass, and needle and thread.

Experimental Design

We obtained statewide mule deer crucial winter range delineations from WGFD for 2007–2013 and compared boundaries to older winter range maps. As boundary changes were minimal, we used the 2013 map as the representative winter range layer from 1980–2013. Similarly, we selected mule deer Hunt Areas that had consistent boundaries and demographic data, resulting in 103 of 140 useable Hunt Areas (74%) from 1995–2013. Digitized boundaries of Hunt Areas were unavailable prior to 2007; therefore, we digitized mule deer Hunt Areas from 1995–2006 using available maps combined with WGFD area boundary descriptions to assure mapping accuracy (ArcGIS Version 10.1, Environmental Systems Research Institute, Redlands, CA). We overlapped sage-grouse Core Area boundaries with crucial winter ranges and intersected areas of commonality to distinguish Core Area overlapped winter range (WR-Core) from non-core overlapped winter range (WR-noncore). We used these spatial regions to evaluate temporal increase in well pads from 1980–2013. Similarly, we intersected Core Area with Hunt Areas to distinguish between Core overlapped Hunt Areas (HA-Core) and non-core Hunt Areas (HA-Noncore). In addition, we calculated the percent overlap of Core Area within individual mule deer Hunt Areas from 1995–2013 to develop categories of percent overlap with Core Area. WR-Core and HA-Core (categories) served as treatments while WR-Noncore and HA-Noncore served as respective controls in our well pad analysis.

We collected data on numbers of active wells from the Wyoming Oil and Gas Conservation Commission (2014) oil and gas well database dating from 1980–2013. Plugged, abandoned, or inactive wells were not included because mule deer exhibit avoidance of active wells (Sawyer et al. 2006). We calculated average well pad size based upon the average size of 100 randomly chosen well pads digitized in GIS (Geographic Information Systems 10.1, ESRI). Using the average well pad size we calculated an average well pad radius of 60 m. If the 60-m radius of a well pad intersected the 60-m radius of another pad these were merged into one well pad. Using GIS, we tallied the number of oil and gas well pads for each year 1980–2013 for winter range and 1995–2013 for Hunt Areas. We analyzed the time frames 1980–2013 for winter range and 1995–2013 for Hunt Areas because lands encompassed by Core Areas served as functional Core Areas even prior to Core Area designation (2008) as evidenced by high sage-grouse population densities (Doherty et al., 2010), and minimal oil and gas development resulting in positive sage-grouse population response (Gamo and Beck, *In review*). In addition, these time frames coincided with consistent boundary delineations for both crucial winter ranges and Hunt Areas and consistent population management objectives for Hunt Areas (S. Smith, personal communication).

Mule deer fawn:female ratio data were obtained from 1995–2013 WGFD Herd Unit and Hunt Area annual reports. The WGFD conducts and compiles annual mule deer winter counts across the state following protocols that are similar to other western states in late November through early December (Rabe et al., 2002). Using visual counts from ground and aerial surveys, animals are classified into adult males, adult females, and fawns and observers strive for sample sizes to meet confidence intervals deemed appropriate for WGFD population estimates (Czaplewski et al., 1983, WGFD, Job Completion Reports, unpublished data). Records of these counts are input into a database and are summarized by the WGFD in annual Job Completion Reports (WGFD unpublished data; Cheyenne). These records provide the input data for herd demographic statistics including numbers of males, females, and fawns counted. The primary change that occurs within Hunt Areas has historically been the number of permits made available. In addition, the focus of harvest has been directed at male animals or in combination with females and fawns being harvested through any deer tags (Job Completion Reports, WGFD). We calculated fawn:female ratios for each Hunt Area for 1995–2013. We then grouped Hunt Areas into multiple quantiles based on their respective land area percentage of overlap with sage-grouse Core Area. Quantiles included <1%, ≥20%, ≥40%, ≥60%, ≥70%, and ≥80% overlap. We considered an overlap of ≤1% as representative of non-core overlap and this level served as a control, whereas other groupings served as treatments.

Statistical Analyses

We utilized analysis of covariance (ANCOVA; PROC GLM, SAS 9.4, SAS Institute, Cary, NC) to compare trends in well pad development between WR-Core and WR-Noncore from 1980–2013. We compared the main effects of WR-Core to WR-Noncore with time being the covariate. We further utilized ANCOVA to evaluate differences in the trend of well pad increases between the HA-Core quantiles (≥20%, ≥40%, ≥60%, ≥70%, ≥80%) and HA-Noncore (<1%). Finally, we utilized ANCOVA to evaluate differences in mule deer fawn:female ratio trends between HA-Core (≥20, ≥40, ≥60, ≥70, ≥80%) and HA-Noncore quantiles (<1%), 1995–2013. The ANCOVA procedure we employed used a suite of 4 models and systematically compared among models to determine the best fit for the comparison among the two trend lines from linear regressions (Weisberg, 1985). The models are as follows:

Model 1- $\hat{y} = b_{0,1}W_1 + b_{0,2}W_2 + b_{1,1}Z_1 + b_{1,2}Z_2$

Model 2- $\hat{y} = b_{0,1}W_1 + b_{0,2}W_2 + b_1X_1$

Model 3- $\hat{y} = b_0 + b_{1,1}Z_1 + b_{1,2}Z_2$

Model 4- $\hat{y} = b_0 + b_1X$

where b_0 is the *y*-intercept, b_1 is the slope estimate, *W* is a label term, *Z* is the value associated with the corresponding *W*, and *X* is time. We first tested model 1 against model 2 to test the null hypothesis that the slopes of Core and Noncore response variables (well pads and fawn:female ratios) trends were identical versus the alternate that they were different ($\alpha = 0.10$). If the null hypothesis was accepted, we then tested model 2 against model 4 to test the null hypothesis that the slopes were identical between Core and non-core areas as well as the *y*- intercepts being identical between the two areas versus the alternate that the slopes were identical but the *y*-intercepts were different. In addition, if upon visual inspection of the plots of the compared slopes the y-intercepts were clearly distinct we first tested model 1 against model 3 to test the null hypothesis that the *y*-intercepts were identical between core and non-core areas versus the alternate that they were different. If the null hypothesis was accepted, we then tested model 3 against model 4 to test the null hypothesis that the *y*-intercepts were identical between Core and non-core areas as well as the slopes being identical between the two areas versus the alternate that the *y*-intercepts were identical but the slopes were different. We tested for normal probabilities and used Ordinary Least Squares assuming residuals were normally distributed. Model significance testing was accomplished using an *F*-test.

The WGFD considers fawn:female ratios higher than 0.66 as indicative of a growing mule deer population whereas lower ratios represent decreasing populations (Unsworth et al., 1999). Thus, to further evaluate the influence of Core Area on mule deer productivity we compared mean fawn:female ratios of the Hunt Area quantiles (<1%, $\geq$20%, $\geq$40%, $\geq$60%, $\geq$70%, $\geq$80%) to a baseline ratio of 0.66 from 1995–2013 using a one-sample *t*-test ($\alpha = 0.05$). We excluded one fawn:female ratio data set from HA-Core with ≥80 Core Area overlap because this observation did not meet sample size requirements for fawn:female ratio analysis (Czaplewski, et al. 1983).

Results

Winter Range Well Pad Density

Total active well pads within mule deer WR-Core increased from 28 in 1980 to 81 in 2013 (Fig. 3) and well pad density increased from 0.3 to 1.0 well pads $\cdot 100\ km^{-2}$ during the same time. Correspondingly, in WR-Noncore, total well pad numbers increased from 840 in 1980 to 2,176 in 2013 and well pad density changed from 5.1 to 13.4 well pads $\cdot 100\ km^{-2}$. The increasing trend in well pads differed ($F_{1,64} = 1383.89$, $p < 0.01$, $r^2 = 0.99$) as WR-Core ($\hat{\beta}_1 = 1.89$, SE = 0.84, $DF_{error} = 64$, $p = 0.03$) was less than WR-Noncore ($\hat{\beta}_1 = 46.04$, SE= 0.84, $DF_{error} = 64$, $p < 0.01$) from 1980–2013.

Hunt Area Well Pad Density

Number of active well pads within mule deer Hunt Areas varied based upon the percent overlap with sage-grouse Core Areas, but all overlap groupings showed increased numbers through time (Table 1). A corresponding change in well pad density was noted as HA-Noncore well pad density increased from 3.1 to 18.2 $\cdot 100\ km^{-2}$ during 1995–2013. Similarly, in HA-Core $\geq$20% well pad density increased from 4.9 to 10.7 $\cdot 100\ km^{-2}$ from 4.3 to 8.3 $\cdot 100\ km^{-2}$ in HA-Core $\geq$40%. HA-Core $\geq$ 60% well pad density changed from 4.9 to 6.7 $\cdot 100\ km^{-2}$ and HA-Core $\geq$70%, well pad density changed from 4.3 to 5.5 $\cdot 100\ km^{-2}$. Finally, HA-Core $\geq$80% well pad density increased from 3.7 to 4.8$\cdot 100\ km^{-2}$ during 1995–2013.

The trend of well pad increase was higher ($p < 0.01$) in HA-Noncore compared to all HA-Core (20%, 40%, 60%, 70%, 80%) quantiles. Specifically, the trend differed ($F_{1,35} = 34.15$, $p < 0.01$, $r^2 = 0.99$) as HA-Core $\geq$20% ($\hat{\beta}_1 = 467.76$, SE = 37.11, $DF_{error} = 34$, $p < 0.01$) was less than to HA-Noncore ($\hat{\beta}_1 = 570.57$, SE = 37.11, $DF_{error} = 34$, $p < 0.01$). Trend of well pad increase in HA-Core $\geq$40% ($\hat{\beta}_1 = 164.81$, SE = 26.84, $DF_{error} = 34$, $p < 0.01$) was different ($F_{1,35} = 85.17$, $p < 0.01$, $R^2 = 0.99$) and less than HA-Noncore ($\hat{\beta}_1 = 570.57$, SE = 26.84, $DF_{error} = 34$, $p < 0.01$). The trend of well pads was also different ($F_{1,35} = 238.8$, $p < 0.01$, $R^2 = 0.98$) as HA-Core $\geq$60% ($\hat{\beta}_1 = 26.34$, SE = 24.90, $DF_{error} = 34$, $p = 0.30$) was less than HA-Noncore ($\hat{\beta}_1 = 570.57$, SE = 24.90, $DF_{error} = 34$, $p < 0.01$). Trends were different ($F_{1,35} = 254.62$, $p < 0.01$, $R^2 = 0.98$) comparing the less increasing trends between HA-Core $\geq$70% ($\hat{\beta}_1 = 10.93$, SE = 24.80, $DF_{error} = 34$, $p = 0.66$) to HA-Core ($\hat{\beta}_1 = 570.57$, SE = 24.80, $DF_{error} = 34$, $p < 0.01$), ($F_{1,35} = 260.12$, $p < 0.01$, $r^2 = 0.98$) and comparing HA-Core $\geq$80% ($\beta = 4.91$, SE = 24.80, $DF_{error} = 34$, $p = 0.84$) to HA-Noncore ($\hat{\beta}_1 = 570.57$, SE = 24.80, $DF_{error} = 34$, $p < 0.01$).

Hunt Area Fawn:female Ratios

Fawn:female ratios varied depending upon how much Hunt Areas overlapped with Core Area. In HA-Noncore (<1% overlap with Core Area) fawn:female ratios averaged 0.64 (range: 0.53–0.73) from 1995–2013 (Table 2). Ratios in HA-Core $\geq$20 and $\geq$40 averaged 0.65 (range: 0.55–0.74) and 0.64 (range: 0.54–0.75), respectively. Ratios in HA-Core $\geq$60% averaged 0.65 (range: 0.52–0.78) over the same time. In HA-Core $\geq$70% fawn:female ratios averaged 0.69 (range: 0.55–0.83) and averaged 0.69 (range: 0.52–0.82) in HA-Core $\geq$80%.

We found no differences ($p > 0.50$) in fawn:female trends comparing HA-Core 20%, 40% and 60% quantiles to HA-Noncore. Results were inconclusive at HA-Core $\geq$70% as the outcomes differed depending on the initial model comparisons. We found similar trends ($F_{1,735}$ = 0.58, p = 0.44) of fawn:female ratios in HA-Core $\geq$70% when evaluating model 1 vs 2 and 2 vs 4. However, when we applied model 1 vs 3 and 3 vs 4; we found the opposite as the trend of fawn:female ratios was different ($F_{1,735}$ = 13.15, p < 0.01, r^2 = 0.04) as HA-Core $\geq$70% ($\hat{\beta}_1$ = -0.001, DF_{error} = 736, p = 0.17) was higher than HA-Noncore ($\hat{\beta}_1$ = -0.005, SE = 0.002, DF_{error} = 736, p = 0.23). Fawn:female ratio trends differed ($F_{1,642}$ = 8.76, p < 0.01, r^2 = 0.03) between the positive trend in HA-Core $\geq$80% ($\hat{\beta}_1$ = 0.00, SE = 0.003, DF_{error} = 641, p = 0.88) compared to the negative trend in HA-Noncore ($\hat{\beta}_1$ = -0.005, SE = 0.003, DF_{error} = 641, p < 0.01) from 1995–2013 (Fig. 4).

Fawn:female ratio means of overlap groupings varied in comparison to the 0.66 reference ratio for productivity (Fig. 5). HA-Non-core fawn:female ratios (mean = 0.63, SE = 0.01, t_{33} = -2.53, p < 0.01) and HA-Core $\geq$20% (mean = 0.64, SE = 0.01, t_{58} = -2.25, p = 0.02), were both <0.66. HA-Core $\geq$40% (mean = 0.64, SE = 0.01, t_{30} = -1.39, p = 0.09) and HA-Core $\geq$60% (mean = 0.65, SE = 0.02, t_{14} = -0.41, p = 0.34) were not different than 0.66. Finally, fawn:female ratio averages in both HA-Core $\geq$70% (mean = 0.69, SE = 0.01, t_9 = 3.68, p < 0.01) and HA-Core $\geq$80% (mean = 0.69, SE = 0.01, t_4 = 2.294, p = 0.04) were higher than the 0.66 threshold for positive productivity (Fig. 5).

Discussion

Wyoming Core Areas were designated to conserve and maintain sage-grouse populations and habitats through a detailed process of planning and managing energy development and other land surface disturbing activities through the implementation of the SGEO (State of Wyoming 2008, 2011). By design, the SGEO limits surface disturbance size and densities at a landscape scale within Core Area boundaries. Thus, a potential benefit of the designation and protections within Core Area is its potential to conserve habitats for other sagebrush utilizing species including mule deer (Gamo et al., 2013). Our first objective was to evaluate whether sage-grouse Core Areas provide protections for mule deer. We evaluated well pad densities by comparing the number of well pads in Core Area overlapped crucial winter range and non-core winter ranges from 1980–2013. We predicted well pad densities would be less in winter range associated with Core Area. In addition, we compared long term annual totals of well pads through time to evaluate differences in trends of well pad numbers within Core and non-core overlapped winter range (1980–2013) and Hunt Areas (1995–2013). In both cases, we found well pad numbers and trends of well pads were lower in Core Area overlapped winter range and Hunt Areas. Our second objective evaluated whether mule deer Hunt Areas overlapped by Core Area received fitness benefits through fawn:female ratios. We found trends in fawn:female ratios began to show potential benefits when overlap with Core Area reached $\geq$70% and more definitively at $\geq$80%. In addition, Hunt Areas with $\geq$70% overlap with Core Area displayed fawn:female ratios averaging higher than 0.66; the threshold of a productive mule deer population (Unsworth et al., 1999). We believe that data to support both objectives may suggest that sage-grouse serve as an umbrella species for mule deer. Accordingly, our analysis of trends of well pads occurring in crucial winter range overlapped with sage-grouse Core Areas combined with the increase in fawn:female ratios in Core Area dominated Hunt Areas provide support for sage-grouse serving as an umbrella for mule deer.

The Wyoming SGEO delineated Core Areas, as mandated through the 2008 Wyoming Governor's Executive Order, provides restrictions with more authority than WFGD winter mule deer stipulation recommendations. Crucial winter range protections, which help limit human associated disturbance, are important as they can reduce impacts to already stressed animals and ultimately impact survival through severe winters (Bartmann and Bowden, 1984; Parker and Robbins, 1984; Bishop et al., 2005). Within the Pinedale, Wyoming area, development on winter range has contributed to reductions in mule deer utilizing the area (WGFD, unpublished report). Mule deer avoided oil and gas infrastructure near Pinedale, Wyoming as development increased over time and deer selected habitats an average of 3.7 km from the nearest well pad (Sawyer et al., 2006). In the Piceance Basin in Colorado, mule deer migratory patterns were disrupted by higher well densities (Lendrum et al., 2012). In south-central Wyoming, increased well pad densities led mule deer to hasten their migratory movements through that landscape (Sawyer et al., 2013). Such changes in wintering and migratory behavior may ultimately influence mule deer survival. Our data demonstrated crucial winter ranges overlapped by sage-grouse Core Areas indeed had much less development, based upon oil and gas well pads, than did non-overlapped Hunt Areas. Suggested SGEO disturbance densities ($1 \cdot 2.6\ km^{-2}$) for Wyoming are about 5-to-7 fold below well pad densities of 2.0 and $2.8 \cdot km^{-2}$ described by Sawyer et al. (2013) and Lendrum et al. (2012), respectively, which are attributed to changes in migratory behavior in mule deer. Thus, Core Areas with historically less development and continued protection ensured by SGEO regulation have limited development to a level much less than that which initiates migratory behavior changes in mule deer.

Similar to the effect on crucial winter ranges, Core Areas provided landscapes of minimized well pad densities within mule deer Hunt Areas. No Hunt Area was completely encompassed by sage-grouse Core Area, but areas with at least 70–80% overlap revealed a higher trend in fawn:female ratios as opposed to non-core overlapped areas. In addition, Hunt Areas with ≥70% overlap with Core Area maintained fawn:female ratios above 0.66 indicative of an increasing population. Unfortunately, only 11 of 103 Hunt Areas (10.7% of total we analyzed) encompassed ≥70% overlap with Core Area. Higher fawn:female ratios for mule deer in areas with less overlap may occur on a more local scale, but we were unable to detect these effects due to the scale of our analysis. Our data provide evidence that Core Area landscapes may contribute to conditions that allow for increased fecundity.

A fortunate outcome of the implementation of the SGEO, particularly through the establishment of Core Areas, is the greater emphasis placed on conserving habitat for sage-grouse over large landscapes likely provides benefits for other species such as mule deer (Gamo et al., 2013; Copeland et al., 2014). In other words, the regulatory nature of the SGEO provides the protections or regulatory status suggested by Hanser and Knick (2011) enhancing sage-grouse' ability to serve as an umbrella species for mule deer. For example, Copeland et al. (2014) found Core Areas overlapped with 66–70% of mule deer migration corridors, 74–75% of stopover areas, and 52–91% of wintering areas for two mule deer populations in western Wyoming. Furthermore, sage-grouse have been proposed as an umbrella species (Rich and Altman, 2001; Rowland et al., 2006; Hanser and Knick, 2011) and specifically for mule deer (Gamo et al., 2013). Umbrella species are a type of surrogate species that may provide conservation benefits to other "background" species (Caro, 2003; Roberge and Angelstam, 2004; Caro, 2010) and, in this case mule deer, overlap with sage-grouse habitat. Noss (1990:360-361) defined surrogate species as "a species with large area requirements, which if given sufficient protected habitat area, will bring many other species under protection." The landscapes encompassed by Core Area (24% of the surface of Wyoming) include 33% of mule deer crucial winter range (Gamo et al., 2013). In their assessment of 10,000 randomly sampled plots, Copeland et al. (2014) found average disruption (number of surface disturbances; e.g., well pads, etc.) was $0.1 \cdot km^{-2}$ and average surface disturbance was 1.6% compared to $3.8 \cdot km^{-2}$ and 5.9% of a developed site, respectively. This suggested mule deer migration corridors overlapped by conserved lands which included Core Area in the upper Green River Basin in Wyoming were afforded better protections than those outside of conserved lands. However, there are other aspects related to oil and gas development including size and arrangements of well pads that may influence use of corridors which were not addressed. Our data, including increased crucial winter range habitat protections from development and fawn:female ratios within overlapped Hunt Areas provide additional support for sage-grouse as an umbrella species. In practice, the SGEO provides a regulatory protection program over a large landscape, which may benefit other species such as mule deer that inhabit Core Areas.

Implications

Landscape conservation practices are becoming more critical in maintaining viable habitats for wildlife species including relatively widespread and abundant rangeland species such as mule deer. In addition to providing protections to mule deer migratory habitat, Core Area landscapes provide protections to 33% of WGFD designated winter range and Hunt Areas. As mule deer populations continue to show declines throughout the West (de Vos et al., 2003) including Wyoming (WGFD, unpublished data) conservation measures that help stem these declines are valuable. Incorporating conservation strategies for other species as an umbrella species concept (Noss, 1990) may in turn provide for broad-scale conservation of associated species (Rowland et al., 2006; Gamo et al., 2013; Copeland et al., 2014). Policies that conserve habitat for sage-grouse across large, undeveloped landscapes may ultimately lead to greater opportunities for mule deer populations across the western United States. For example, a simple extrapolation of our data using the higher fawn:female ratios in 70–80% overlap of Core Area (0.69) compared to 0.64 in non-core Hunt Areas suggests a 5 fawn increase for every 100 females; 500 fawn increase for every 10,000 females; and a 5,000 fawn increase for every 100,000 females. Rangeland carrying capacity, disease, drought, predation, and other factors may limit recruitment of these extrapolated individuals into actual mule deer populations; however, they do suggest the relative greater capacity for mule deer populations to rebound in Hunt Areas with ≥70% Core Area.

Acknowledgments

Our research would not have been possible without the efforts of the many WGFD biologists who collected mule deer herd demographic data. In particular, we thank David Legg, University of Wyoming, for his critical assistance with statistical analyses. Matthew Kauffman, Roger Coupal, Kurt Smith, and Peter Stahl, University of Wyoming all provided helpful insights in regard to study design and analyses. We also thank Mary Flanderka, John Emmerich, and John Kennedy from WGFD for their support. Brian Brokling and Troy Gerhardt processed spatial data for use in analyses. Our research was supported by WGFD Grant Number 0020011.

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Table 1. Active well pads in mule deer Hunt Areas with <u><</u>1% (non-core, control Hunt Areas), 20%, 40%, 60%, 70%, and 80% overlap with sage-grouse Core Area in Wyoming, United States, 1995–2013.

	Well Pads					
Year	≤ 1%	≥ 20%	≥40%	≥60%	≥70%	≥80%
1995	1604	5532	2591	1218	766	320
1996	1622	5184	2630	1239	779	328
1997	1668	5819	2687	1252	784	330
1998	1768	6043	2749	1268	791	333
1999	1910	6294	2808	1288	795	333
2000	2331	6552	2860	1301	796	333
2001	2965	6840	2941	1324	815	333
2002	3566	7195	3051	1336	823	333
2003	4057	7380	3013	1240	826	333
2004	4744	7739	3120	1249	826	326
2005	5821	8354	3355	1263	834	327
2006	7061	9034	3795	1442	841	331
2007	8163	9911	4159	1458	846	334
2008	8230	10591	4443	1478	858	337
2009	9065	13207	5152	1656	914	391
2010	9382	13667	5238	1673	920	392

2011	9748	11804	4852	1589	943	410
2012	9946	12033	4955	1623	961	416
2013	9456	12155	5004	1659	978	418

Table 2. Mean fawn:female ratios (SE) in mule deer Hunt Areas with ≤1% (non-core), 20%, 40%, 60%, 70%, and 80% overlap with sage-grouse Core Area in Wyoming, United States, 1995–2013.

	Fawn:female ratios with Core Area overlap					
Year	≤1% *n* = 28	≤20% *n* = 54	≤40% *n* = 28	60% *n* = 15	70% *n* = 11	80% *n* = 5
1995	0.68 (0.02)	0.65 (0.02)	0.68 (0.04)	0.71 (0.06)	0.71 (0.08)	0.77 (0.15)
1996	0.69 (0.03)	0.71 (0.02)	0.71 (0.03)	0.71 (0.04)	0.68 (0.05)	0.65 (0.05)
1997	0.63 (0.03)	0.68 (0.02)	0.70 (0.02)	0.72 (0.03)	0.74 (0.04)	0.72 (0.06)
1998	0.73 (0.04)	0.74 (0.02)	0.75 (0.03)	0.78 (0.04)	0.83 (0.05)	0.82 (0.07)
1999	0.71 (0.02)	0.72 (0.02)	0.73 (0.03)	0.74 (0.04)	0.73 (0.05)	0.65 (0.07)
2000	0.64 (0.03)	0.64 (0.02)	0.61 (0.03)	0.60 (0.03)	0.60 (0.02)	0.62 (0.03)
2001	0.53 (0.03)	0.55 (0.02)	0.54 (0.03)	0.52 (0.04)	0.55 (0.04)	0.53 (0.04)
2002	0.56 (0.03)	0.60 (0.02)	0.58 (0.03)	0.58 (0.04)	0.59 (0.04)	0.52 (0.03)
2003	0.68 (0.03)	0.68 (0.02)	0.66 (0.03)	0.62 (0.05)	0.64 (0.06)	0.59 (0.10)
2004	0.61 (0.02)	0.66 (0.02)	0.67 (0.03)	0.69 (0.05)	0.71 (0.05)	0.65 (0.07)
2005	0.72 (0.04)	0.68 (0.02)	0.70 (0.02)	0.73 (0.03)	0.77 (0.03)	0.74 (0.04)
2006	0.65 (0.02)	0.63 (0.02)	0.61 (0.02)	0.60 (0.03)	0.64 (0.02)	0.67 (0.03)
2007	0.63 (0.02)	0.62 (0.02)	0.61 (0.02)	0.61 (0.04)	0.66 (0.04)	0.70 (0.05)
2008	0.59 (0.03)	0.63 (0.02)	0.65 (0.02)	0.66 (0.03)	0.71 (0.03)	0.70 (0.04)

2009	0.65 (0.03)	0.60 (0.01)	0.62 (0.02)	0.63 (0.03)	0.67 (0.04)	0.67 (0.06)
2010	0.59 (0.02)	0.62 (0.02)	0.64 (0.02)	0.66 (0.04)	0.71 (0.05)	0.75 (0.06)
2011	0.60 (0.02)	0.60 (0.02)	0.61 (0.03)	0.62 (0.04)	0.65 (0.04)	0.65 (0.05)
2012	0.63 (0.04)	0.59 (0.02)	0.58 (0.03)	0.59 (0.04)	0.62 (0.05)	0.57 (0.07)
2013	0.58 (0.03)	0.60 (0.02)	0.58 (0.03)	0.57 (0.04)	0.63 (0.04)	0.70 (0.06)

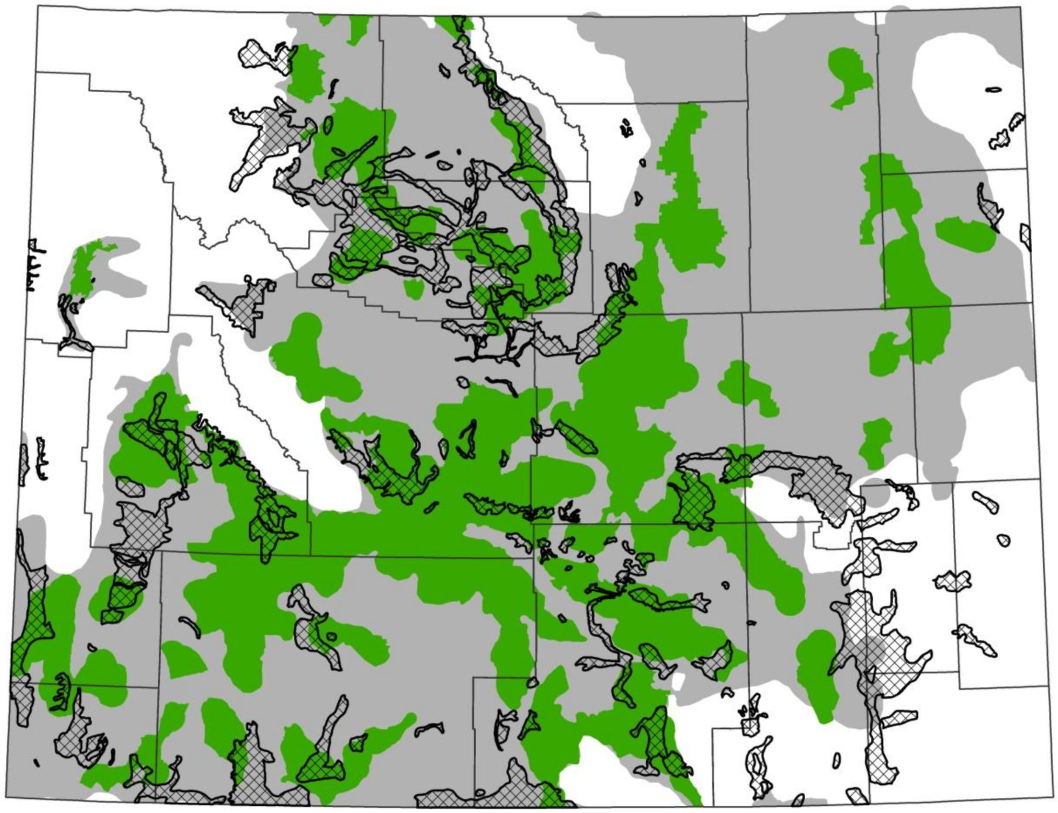

Figure 1. Mule deer crucial winter range (hashed polygons) overlaying sage-grouse Core Areas in green in Wyoming, United States, 1980-2013. Gray shading indicates current distribution of sage-grouse (Schroeder et al. 2004). Mule deer and Core Area delineations by Wyoming Game and Fish Department (Core Area Version 3, State of Wyoming 2010).

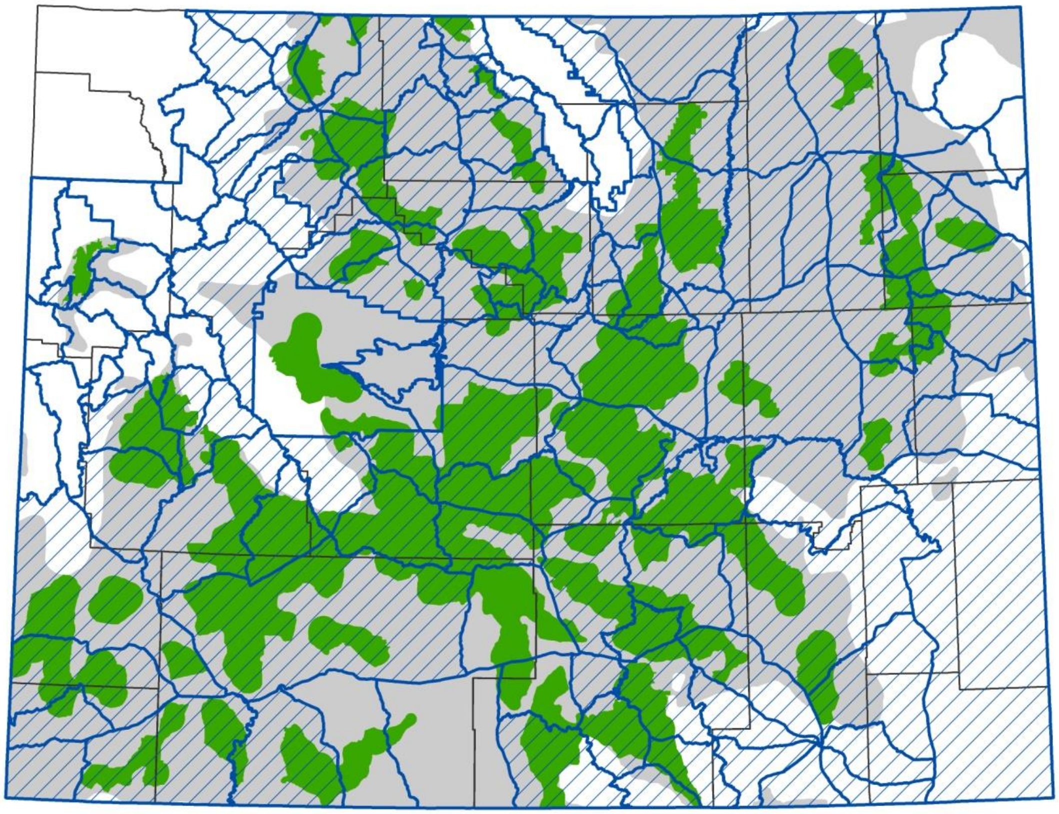

Figure 2. Location of 103 (blue hatched) of 140 (outlined in blue) current (2015) Wyoming Game and Fish Department Mule Deer Hunt Areas overlayed on 31 core sage-grouse population areas (green-shaded areas), Wyoming, United States, 1995-2013. Gray-shaded areas represent sage-grouse range where non-core sage-grouse populations occur within current sage-grouse range (Schroeder et al. 2004). Mule deer and Core Area delineations by Wyoming Game and Fish Department (Core Area Version 3, State of Wyoming 2010).

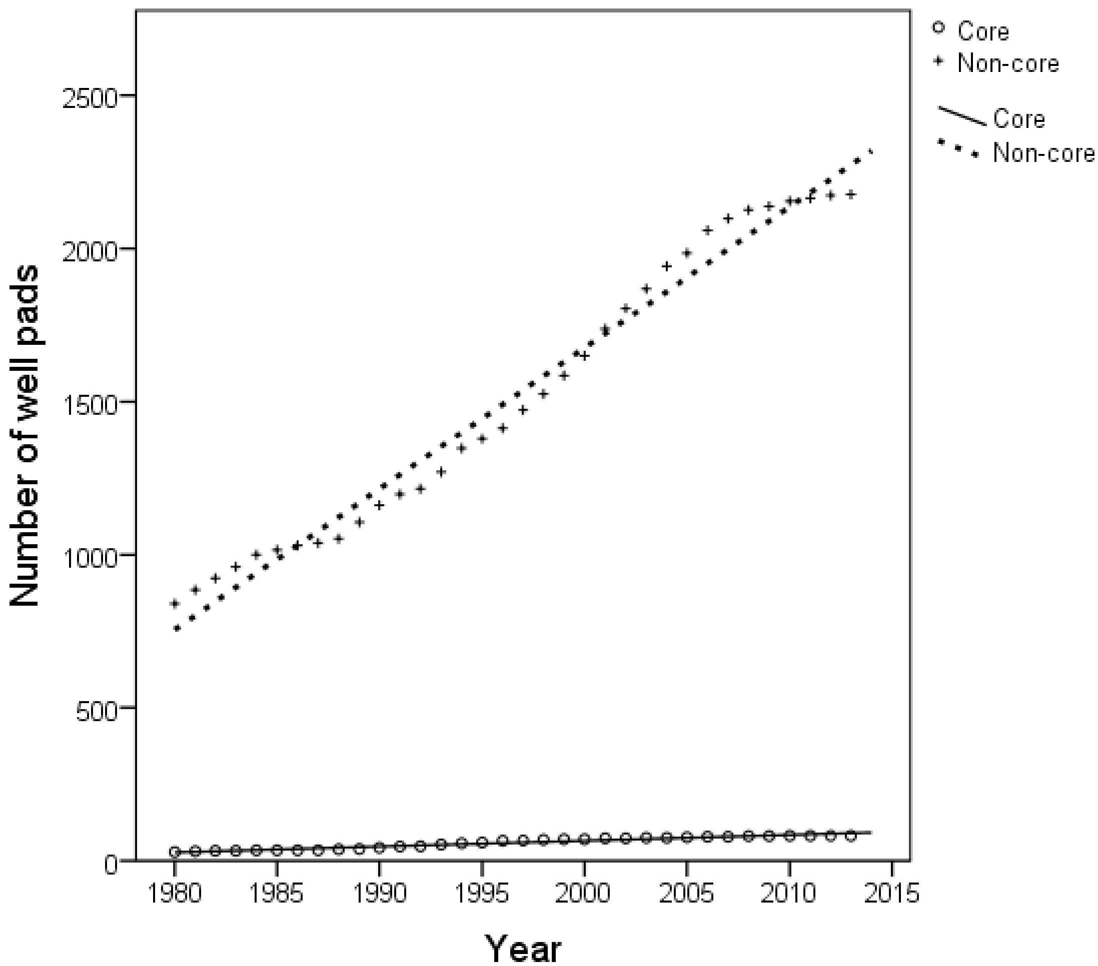

Figure 3. Well pad comparison between Core and non-core sage-grouse population areas overlapped with mule deer crucial winter range areas in Wyoming, United States, 1980–2013. Linear trend lines are provided for comparisons.

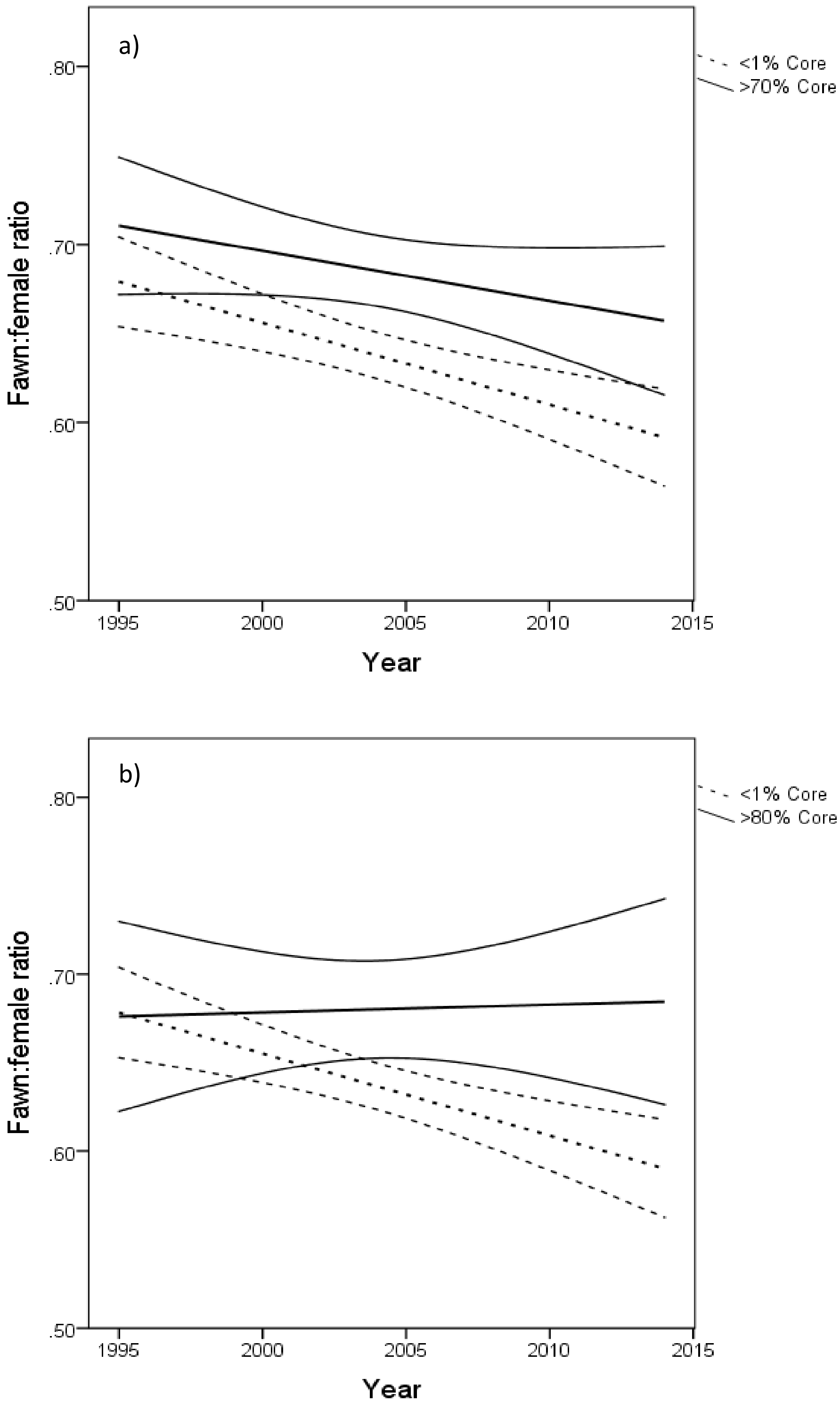

Figure 4. Fawn:female ratio comparison between (a) ≥70% and (b) ≥80% Core versus. <1% non-core overlapped mule deer Hunt Areas in Wyoming, United States, 1995–2013. Linear trends with 95% confidence intervals are provided for comparisons.

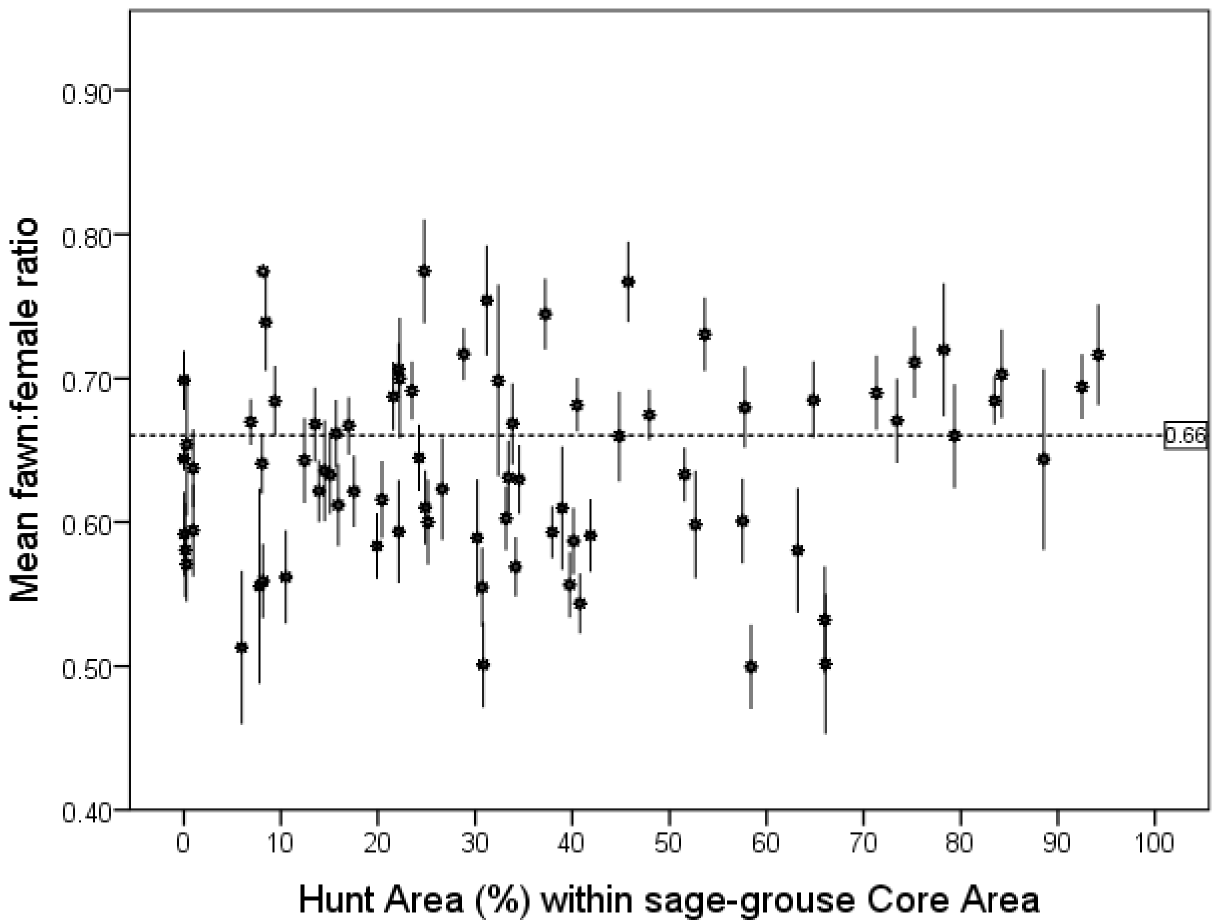

Figure 5. Mean fawn:female ratios (± SE) by the percentage Core Area overlap in 104 Hunt Areas, Wyoming, United States, 1995–2013. The dashed horizontal line indicates a level (0.66) for fawn:female ratios above which populations are increasing.

CHAPTER FOUR

IMPACTS OF ENERGY DEVELOPMENT ON HUNTER SUCCESS FOR MULE DEER AND PRONGHORN IN WYOMING

RH: IMPACTS OF ENERGY DEVELOPMENT ON HUNTER SUCCESS

R. SCOTT GAMO[1], Wyoming Game and Fish Department and Department of Ecosystem Science and Management, University of Wyoming
Laramie, WY 82071
E-mail:scott.gamo@wyo.gov; Phone-307-777-4509

KURT T. SMITH, Department of Ecosystem Science and Management
University of Wyoming
Laramie, WY 82071

JEFFREY L. BECK, Department of Ecosystem Science and Management
University of Wyoming
Laramie, WY 82071

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[1]*E-mail: scott.gamo@wyo.gov*

KEYWORDS: *Antilocapra americana*, harvest, mule deer, *Odocoileus hemionus*, oil and gas development, pronghorn**,** resource extraction, Wyoming

ABSTRACT

Infrastructure associated with energy development influences hunter access and introduces disturbance activities to landscapes that can influence habitat selection and behavior of ungulates. Consequently, habitat loss and hunter access concerns must be addressed by wildlife managers as they consider management of populations of western big game species including mule deer (*Odocoileus hemionus*) and pronghorn (*Antilocapra americana*). We evaluated whether increased energy development, as quantified through change in well pads, has impacted hunter success of mule deer and pronghorn. Because ungulates tend to avoid energy

development, we also evaluated whether hunting statistics can be used to identify potential impacts of energy development on mule deer and pronghorn. We included data from 22 of 39 mule deer and 34 of 46 pronghorn Herd Units across Wyoming from 1980 to 2012. Well pads across mule deer Herd Units increased from 1,040 in 1980 to 9,689 in 2012, and well pads in pronghorn Herd Units increased from 1,359 to 15,251 during the same time period. Our results indicated that hunter success (%) for mule deer in Wyoming was positively associated with number of well pads and a decrease in hunter effort, whereas pronghorn hunter success in Wyoming was unaffected by increasing well pads. We identified a change in mule deer harvest success attributable to increasing energy development; however, harvest statistics were not informative in identifying impacts from energy development on pronghorn populations.

Ungulate habitat and population management is increasingly complex as habitats continue to be subject to expanding human influences from energy extraction, industrialization, agricultural development, and urbanization. For example, the global demand for energy is estimated to increase by 40% within the next 20 years, leading to elevated coal, gas, oil, and renewable energy development (International Energy Agency 2015), which is projected to result in >200,000 km^2 of land utilized by various forms of energy development in the United States by 2035 (McDonald et al. 2009). Human-created surface disturbances such as mines, oil and gas well pads, logging, and roads contribute to habitat use changes by caribou (*Rangifer tarandus*; Cameron et al. 2005, Vors et al. 2006, Sorensen et al. 2007, Polfus et al. 2011), elk (*Cervus elaphus*; Thomas et al. 1979, Lyon 1983, Kuck et al. 1985, Millspaugh et al. 2000, Rowland et al. 2000, Rumble and Gamo 2011, Webb et al. 2011, Buchanan et al. 2014), mule deer (*Odocoileus hemionus*; Rost and Bailey 1979, Thomas et al. 1979, Medcraft and Clark 1986, Gamo and Anderson 2002; Sawyer et al. 2006, 2009; Lendrum et al. 2012, Sawyer et al. 2013), and pronghorn (*Antilocapra americana*; Ockenfels et al. 2000, Gamo and Anderson 2002, Sheldon 2005, Gavin and Komers 2006, Beckman et al. 2012).

Impacts to ungulates from energy development have often been associated with human activity caused by traffic on roads (e.g., Sawyer et al. 2006). Energy development often includes increased road networks (Bureau of Land Management [BLM] 2003) to facilitate transportation of material, equipment, and personnel to and from well pads and other infrastructure points. In addition to increasing activity, increases in energy development and its associated increase in roads may impact hunter distributions through enhanced access to potential hunting areas (Gratson and Whitman 2000, Lebel et al. 2012). Hunter access influences harvest of ungulates as Gratson and Witman (2000) found that as hunter densities increased due to more road access, harvest success decreased. Others have noted that elk mortality, mainly due to harvest, increases with increased roads and hunter densities (Unsworth et al. 1993, Cole et al. 1997, Hayes et al. 2002, McCorquodale et al. 2003). In addition, increased road networks within intensively farmed areas in Minnesota likely contributed to greater white-tailed deer (*O. virginianus*) vulnerability to hunting (Brinkman et al. 2004). In comparison, increasing energy development and associated changes in access present additional challenges for wildlife managers to address.

Traditional means of evaluating energy-related impacts to ungulates has included time and funding intensive studies, often using GPS- or radio-collared animals to model potential changes in habitat selection and use of developed areas (e.g., Sawyer et al. 2006, 2009; Buchanan et al. 2014). However, harvest data are readily available and are generally integrated into annual monitoring plans by state wildlife agencies to obtain critical information for big game population management. The Wyoming Game and Fish Department (WGFD), similar to other western state wildlife agencies, annually collects a variety of herd and hunt statistics including harvest (%; hunter success), hunter effort (days until harvest), herd age ratio, and number of hunters per Herd Unit (Rupp et al. 2000, Rabe et al. 2002). Big game populations are increasingly exposed to higher levels of disturbances in states such as Wyoming where energy development continues to expand. Evaluating ungulate population response to anthropogenic impacts such as energy development may be possible through correlation of anthropogenic infrastructure with annual harvest and herd status data. Increased road networks developed to access energy resources, may increase hunter access but they may also increase avoidance of habitat by big game species. Analyses of these data may provide managers with meaningful information to better manage ungulate populations in landscapes facing increasing energy development.

Our primary objective was to evaluate whether increased energy development, as quantified through change in well pad densities, has impacted hunter success on mule deer and pronghorn in Wyoming. Because ungulates tend to seasonally avoid energy development, it may be expected that hunter success would be negatively related to development activities; however, increased hunter access has been associated with increased hunter success in ungulate populations. Therefore, we predicted that avoidance behaviors of mule deer and pronghorn associated with development would result in lower hunter success. The alternative prediction is the likely increased access associated with increased energy development should result in greater success for mule deer and pronghorn hunters.

STUDY AREA

Our analysis included data from 22 of 39 (56.4%) WGFD mule deer (Figure 1) and 34 of 46 (73.9%) pronghorn (Figure 2) Herd Units that occur across Wyoming, with the exception of national parks. The boundaries of the Herd Units we included in our evaluations have remained consistent over the 30 years we assessed (S. Smith, pers. comm.) and were delineated and mapped by WGFD staff through annual ground or aerial observations of areas frequented by mule deer and pronghorn. Herd Units encompass ungulate populations in a diversity of forest, sagebrush (*Artemisia* spp.), and short-grass prairie ecosystems throughout Wyoming (Knight et al. 2014). Areas where energy development and Herd Units overlap most often co-occur within the sagebrush-dominated basins in the western and northeastern portions of Wyoming. The Wyoming Basin occurs within the western half of Wyoming and consists of multiple basins between mountain ranges (Rowland and Leu 2011). Major basins include the Bighorn, Great Divide, Green River, and Shirley. Vegetation in these basins generally consists of shrub steppe dominated by Wyoming big sagebrush (*A. tridentata wyomingensis*), but also includes areas of black (*A. nova*) and low sagebrush (*A. arbuscula*; Rowland and Leu 2011, Knight et al. 2014). Common grasses include bluebunch wheatgrass (*Pseudoroegneria spicata*), needle and thread (*Hesperostipa comata*), western wheatgrass (*Agropyron smithii*), and a variety of blue grasses (*Poa* spp.) Cheatgrass (*Bromus tectorum*), an invasive annual is becoming more common.

Northeastern Wyoming rangelands, including the Powder River Basin, consist of sagebrush-dominated shrub steppe assimilating with mixed grass prairie towards the South Dakota border (Knight et al. 2014). Shrub steppe habitat is characterized by Wyoming big sagebrush, silver sagebrush (*A. cana*) and a diversity of herbaceous plants composing the understory. Common forbs include desert alyssum (*Alyssum desertorum*), milkvetches, and scarlet globemallow. Common native grasses include blue grama (*Bouteloua gracilis*), bluebunch wheatgrass, prairie junegrass (*Koeleria macrantha*), and western wheatgrass. Non-native grasses include crested wheatgrass (*Agropyron cristatum*) and cheatgrass (Thelenius et al.

1994). Rocky Mountain juniper (*Juniperus scopulorum*) and ponderosa pine (*Pinus ponderosa*) occur on rocky uplifts and in river drainages.

Herd Units lying entirely within mountain ranges in Wyoming typically do not overlap with energy development. However, Herd Units overlapping mountain ranges with adjacent foothills and rangelands typically include some level of energy or extractive resource development. Wyoming mountain ranges encompass temperate forests with species including Douglas fir (*Pseudotsuga menziesii*), Englemann spruce (*Picea engelmannii*), lodgepole pine (*Pinus contorta*), ponderosa pine (*P. ponderosa*), and quaking aspen (*Populus tremuloides*). The shortgrass prairie in the southeast corner of the state is composed of grasses including blue grama, buffalo grass (*Bouteloua dactyloides*), western wheatgrass, and needle and thread.

METHODS

Study Design

We evaluated hunter success (%) from 1980 to 2012 for mule deer and pronghorn in Wyoming. We utilized WGFD harvest data collated and calculated at the Herd Unit level across the state on an annual basis (Job Completion Reports, WGFD). The 22 mule deer and 34 pronghorn Herd Units we selected for our analyses had consistent boundaries and data collection over the 1980–2012 timeframe. These Herd Units also provided good geographical representation of the state (Figures 1 and 2). The WGFD administered both general and limited draw hunts for each ungulate species. The designation of hunts can change from year to year within the Hunt Areas that contribute to Herd Units in regard to season length and tag allocation based on estimated animal abundance. The primary change that occurred within Hunt Areas has historically been the number of permits made available. In addition, the focus of harvest has been directed at male animals or in combination with females and fawns being harvested through any deer or any antelope tags (Job Completion Reports, WGFD). WGFD uses a solicited mailed or online hunter report system to collect hunter related data. Statistics determined from these data include hunter success, hunter effort, and number of hunters. Hunter success was the percentage of license holders who were reported to be successful in harvesting a deer or pronghorn each year within respective Herd Units. Hunter effort was the average number of days hunted and included both successful and unsuccessful hunters. Number of hunters was the total number of hunters for each species in each Herd Unit and was reflective of available permits. We recognize that changes in season structure in individual Hunt Areas within Herd Units may contribute to variation in reported harvest data; however, hunter effort and hunter numbers likely reflected yearly variation in season structure changes.

We used well pads as a surrogate measure of energy development, similar to Harju et al.'s (2010) study on oil and gas impacts on male greater sage-grouse (*Centrocercus urophasianus*) lek attendance in Wyoming. We argue that our choice of well pads as an explanatory variable to evaluate how energy development may have influenced hunter access was logical because: 1) it has been reported that one natural gas well is, on average, accompanied by 2 km of roads (BLM 2003), and 2) data on road network expansion in oil and gas fields were not readily available across the 33-year period of our study, whereas well pad data were. We thus reasoned that areas with greater numbers of well pads were positively related to greater access, resulting in higher potential impacts from energy development on hunter success. We collected active well data from the Wyoming Oil and Gas Conservation Commission (WOGCC) oil and gas well database from 1980 through 2012 (WOGCC 2012). We only considered active wells when they were in operation as impacts to mule deer have been shown to be associated with activity on and near well pads (Sawyer et al. 2006). We calculated average well pad size based on the average size of 100 randomly chosen well pads from across the state digitized in a Geographic Information System (GIS; mean = 60-m radius; ESRI ArcGis; Ver. 10.1). We computed the number of well pads in each mule deer or pronghorn Herd Unit by applying a 60-m radius to each well location. If the estimated radius of a well pad intersected another well pad, we merged pads together and considered them to be a single well pad.

We determined annual precipitation within each Herd Unit using data acquired from the DayMet weather information system (Thornton et al. 1997). We randomly selected 5 points from each Hunt Area within Herd Units for each year from 1980–2012. At each point we obtained weather data to estimate annual precipitation. We averaged precipitation across all the points within a Herd Unit to quantify annual precipitation for that unit. Within a GIS, we calculated the percentage of public land (state and federal) within each Herd Unit by intersecting Herd Unit boundaries with public and private ownership overlays. We included land ownership to account for potential differences in access between public and private lands as restrictions to access are typically less on public lands.

Analyses

We used mixed effects multiple linear regression analyses to evaluate the influence of predictor variables on hunter success for mule deer and pronghorn separately across Wyoming. We included the following fixed effects variables for each year (1980–2012) in each Herd Unit; number of well pads (well pads), number of hunters (hunters), hunter effort (effort), hunter success (% success), annual precipitation, and public land % (federal and state). We included Herd Unit as a random intercept term to account for serial correlations with Herd Units through time. Prior to modeling we assessed collinearity among predictor variables and did not allow variables to compete in the same model if $r \geq |0.7|$. We visually inspected residual plots to assess linearity and homoscedasticity. We included a quadratic term for hunter effort because of a non-linear relationship with hunter success and better model fit for both mule deer and pronghorn. To account for seasonal changes in harvest regulations (i.e., season length and tag allocation) we included number of hunters and hunter effort in all models. For ease of model coefficient interpretation we rescaled hunter effort by dividing by 7 to convert the number of days to harvest a mule deer or pronghorn to weeks. Similarly, we rescaled number of hunters, precipitation, public land, and number of well pads by dividing values by 1000. We used an information-theoretic approach to assess variable importance for each assessment, where we evaluated all possible combinations of the predictor variables (with effort and number of hunters included in every model) that we hypothesized to influence the response variables of hunter success (Arnold 2010). For each model, we calculated Akaike's Information Criterion adjusted for small sample sizes (ΔAICc), and Akaike weights (w_i; Burnham and Anderson 2002, 2004) to initially rank the candidate models. We allowed all variable combinations to compete in an AIC framework and considered models to be competitive when ΔAICc $\leq$4, relative to the top competing model (Arnold 2010). If models were competitive, we calculated model-averaged parameter estimates and 95% confidence intervals based on unconditional standard errors. Model averaging minimized the effects of uninformative parameters, providing a more conservative assessment of the importance of variables (Arnold 2010, Doherty et al. 2012). All statistical analyses were conducted using R statistical software using packages lme4, MuMIn, and AICcmodavg (Barton et al. 2015, Bates 2015, Mazerolle 2015, R Development Core Team 2015).

RESULTS

We evaluated 726 Herd Unit by year combinations across 33 years (1980–2012) within 22 mule deer Herd Units with consistent data collection and boundaries within Wyoming. In mule deer

Herd Units, hunter success averaged 50.4% (range: 3.8–95.9%) across years and hunter effort averaged 9.2 days (range 1.7–58.1 days) per Herd Unit. Average number of mule deer hunters in each Herd Unit was 1,823.3 (range: 18–13,686). Annual precipitation in mule deer Herd Units averaged 39.0 cm (range: 7.9–153.4 cm) and the average number of active well pads was 160.7 (range: 0–4,291). Five of 22 (22.7%) of mule deer Herd Units contained 0 well pads. For pronghorn, we examined 34 Herd Units across 33 years that met our criteria totaling 1,122 Herd Unit by year combinations. Pronghorn hunter success averaged 93.2% (range: 59–100%), whereas pronghorn hunter effort averaged 2.9 days (range: 1.1–20.0 days). Average number of pronghorn hunters across Herd Units was 797.5 (range: 36.0–5,509). Annual precipitation in pronghorn Herd Units averaged 39.0 cm (range: 13.7–101.2 cm), and average number of active well pads was 161.1 (range: 0–5,602). Ten of 34 (29.4%) pronghorn Herd Units had 0 well pads.

The evaluation of hunter success on mule deer harvest resulted in 8 total models, 3 of which were competitive ($\Delta AIC_c \leq 4$) and were considered further (Table 1a). Model averaging indicated that the 95% confidence intervals for the estimates of annual precipitation, percent public land, and total number of mule deer hunters overlapped 0 (Table 1b); therefore we considered those to be marginal predictor variables and limited our interpretation primarily to well pads and hunter effort. Mule deer hunter success was positively correlated with a decrease in hunter effort ($\hat{\beta}_1$ = -0.268, SE = 0.013; Figure 3a) and an increase in well pads ($\hat{\beta}_1$ = 0.025, SE = 0.009; Figure 3b). The quadratic relationship between hunter success and effort suggested that success was negatively correlated with hunter effort to an intermediate point, where after effort no longer negatively affected success.

Evaluation of hunter success on pronghorn harvest resulted in 7 competitive models ($\Delta AIC_c \leq 4$; Table 2a). Model averaging indicated that the 95% confidence interval for the odds ratio estimate of annual precipitation, percent public land, total number of pronghorn hunters, and number of well pads, overlapped 0 (Table 3b); therefore we considered those to be marginal predictor variables and limited our interpretation primarily to hunter effort. Pronghorn hunter success increased with a corresponding decrease in hunter effort ($\hat{\beta}_1$ = -0.33, SE = 0.026; Figure 3c). There was no meaningful relationship between hunter success and well pad numbers (Figure 3d).

The trend in average mule deer hunter success across Herd Units did not change proportionally with average numbers of well pads as it remained relatively constant through time (between 40–60% through 1980–2012), whereas well pads in mule deer Herd Units increased 9.3-fold over the same time period from 1,040 in 1980 to 9,689 in 2012 (Figure 4a). Pronghorn success rates remained high through time (above 90%) while average number of well pads in pronghorn Herd Units increased 11.2-fold from 1,359 in 1980 to 15,251 in 2012 (Figure 5a). Mean hunters per Herd Unit generally decreased across time in mule deer Herd Units (Figure 4b) reflective of fewer allocated licenses, whereas pronghorn hunter numbers fluctuated through time (Figure 5b).

DISCUSSION

Energy development can influence access to animals and introduce additional human disturbance activities that can impact ungulate use of and survival in impacted landscapes (Sawyer et al. 2006, Beckman et al. 2012, Lendrum et al. 2012, Sawyer et al. 2013, Buchanan et al. 2014, Taylor et al. 2016). A better understanding of how increased development affects harvest dynamics may be useful to managers as they consider potential impacts when designing annual harvest strategies to manage big game populations. Regulated harvest is an effective tool for managing many wild ungulate populations (Stedman et al. 2004) and is extensively utilized by state agencies to reach management objectives (Rupp et al. 2000). We investigated the usefulness of harvest parameters (hunter success) as an indicator of impacts of extractive resource development on mule deer and pronghorn. Specifically, we evaluated whether increased energy development, as measured by increased number of well pads, impacted hunting success. Our original expectation was that any impact we might detect would be negative; consistent with the science of oil and gas development on mule deer (Sawyer et al. 2006, Sawyer et al. 2009) and pronghorn habitat (Beckman et al. 2012). Certainly, increasing development typically does not benefit many wildlife species such as mule deer and pronghorn as habitat use and behavioral impacts to these species have been identified (Sawyer et al. 2006, Beckman et al. 2012, Lendrum et al. 2012, Sawyer et al. 2013). Alternatively, increased hunter access by way of increased roads influences ungulate harvest (Unsworth et al. 1993, Gratson and Witman 2000, Hayes et al. 2002, McCorquodale et al. 2002, Brinkman et al. 2004), and may be reflected in harvest statistics. Our analysis suggested that hunter success for mule deer was positively associated with increased well pads; however, we found the number of well pads did not influence pronghorn hunter success. Rather, hunter success was most associated with increased hunter effort. Secondarily, we predicted mule deer and pronghorn harvest success would be informative for determining energy impacts. Analyses of harvest statistics did suggest a relationship with mule deer harvest success attributable to energy development but the same statistics were uninformative for identifying impacts to pronghorn. In addition, as the impact to mule deer was not detrimental as typically revealed from impact studies (e.g., avoidance of habitats, change in population size, etc.) the use of agency collected harvest data, in our case hunter success, is likely not useful in identifying finer scale impacts as can be done with more traditional means of telemetry-based and site specific studies.

Mule deer hunting occurs across Wyoming in undeveloped mountain ranges, across intermountain basins, and within shortgrass prairies. Energy development occurred across 77% of the 22 Herd Units we examined. Despite increased energy development across Wyoming and corresponding increase in roads and associated infrastructure (BLM 2003), hunter success was stable and slightly increased over the 33-year period we examined. The increase in hunter success may be influenced by access facilitated by energy development. These results mirror findings from studies on elk, black-tailed deer (*O. h. sitkensis*), and white-tailed deer that reported greater hunter-associated mortality associated with increased access (Unsworth et al. 1993, Farmer et al. 2006, Lebel et al. 2012). Similarly, Swenson (1982) found that mule deer in open habitats were more vulnerable to hunting. Others (Gratson and Whitman 2000) found elk harvest decreased on a per-hunter basis with increased road access where hunters on foot or off road vehicles had greater success. This may appear contradictory to what would be expected as many studies have documented avoidance behavior by ungulates when extractive energy development increases (e.g., Lendrum et al. 2012; Sawyer et al. 2006, 2009, 2013; Buchanan et al. 2014). However, these studies have evaluated relatively fine scale habitat use in response to development and have not considered increased access through development at the Herd Unit level as we have assessed here.

Like mule deer Herd Units, pronghorn units experienced large increases in well pad numbers from 1980–2012 indicating an expanding road network and concomitant greater hunter access. Not surprisingly, pronghorn hunting occurs within developed areas and approximately 70% of the 34 pronghorn Herd Units we examined contained well pads. Proximity to major roads was one of 3 factors related to higher winter mortality risk of pronghorn in the Shirley Basin of Wyoming (Taylor et al. (2016), and Beckman et al. (2012) suggested pronghorn selection of winter habitats was negatively influenced by oil and gas development. However, others have noted unaffected season long use by pronghorn of impacted areas such as reclaimed coal mine lands (Medcraft and Clark 1986, Gamo and Anderson 2002). Wyoming historically has had large pronghorn populations with statewide populations often exceeding 300,000 individuals (Yoakum 2004a; WGFD, unpublished data). Typically, size of pronghorn populations is most influenced by weather events, particularly during severe winters that can cause population declines (Martinka 1967, Barret 1982). Pronghorn habitat may be negatively influenced or impacted from energy development (Beckman et al. 2012), but in general, there is less supportive evidence of this than for mule deer (e.g., Taylor et al. 2016). Pronghorn populations continue to utilize habitats within certain types of development (Medcraft and Clark 1986, Gamo and Anderson 2002, Beckmann et al. 2012, Taylor et al. 2016), and may better tolerate human activity as by readily habituating to anthropogenic activities (O'Gara 2004, but see Beckmann et al. 2012). Pronghorn exist in relatively high numbers across Wyoming and it was not surprising to see consistently high success rates by pronghorn hunters as this species is generally more easily hunted in the open rangelands characterizing their habitat (Yoakum 2004b).

Wyoming mule deer populations decreased approximately 33% (WGFD, unpublished data) during our study period, which is concurrent with West-wide declines in mule deer populations (deVos et al. 2003). Our data revealed decreases in hunter numbers during the same time period reflecting a decrease in permit allocation. Accordingly, wildlife managers have made annual adjustments in hunting seasons to accommodate declining mule deer populations (Stedman et al. 2004) and have been able to maintain a relatively consistent level of harvest success albeit harvesting fewer animals. Annual adjustments to hunting seasons are typically based upon data collected each year, which provides current demographic information (Rabe et al. 2002). This system enables managers to account for fluctuating ungulate populations. In Wyoming, annual permit allocations are subject to change implemented by managers to meet management goals based not only on annual data collection, but public input that begets season setting. Public input during the season setting process can ultimately influence final permit numbers. Adjustments made during the season setting process that include the balance of management efforts to track wildlife population and public opinion likely preclude the ability to fully utilize harvest metrics, such as hunter success, for evaluating potential impacts on populations or habitats from energy development. In other words, the lack of stability and consistency between annual permit allocations inhibits the ability to determine if strong relationships exist between population attributes and outside influences such as energy development using agency collected data. We have demonstrated that analyses of harvest metrics can provide managers with insight on the effects of hunting on some game species; specifically that increased development influences hunter success of mule deer. However, more fine scale experiments are necessary to evaluate the influence of local scale development and concomitant increased access on hunter success.

MANAGEMENT IMPLICATIONS

Hunting seasons provide a critical opportunity to collect data that aids wildlife agencies in managing ungulate populations (Stedman et al. 2004). Managers use harvest data to assist them in developing hunting strategies to maintain or reach population goals. In Wyoming, where oil and gas development is a prevalent feature across the state, we found that increasing energy development paralleled increased harvest success of mule deer, but not pronghorn. Our results suggest that analyses of harvest metrics can provide managers with insight to other effects of increased development on mule deer including its likely influence on hunter access. This information is important as managers can plan for these impacts as they determine permit numbers and allocation of those permits to reach overall Herd Unit population goals. It is imperative that managers monitor demographic and habitat data for the herds they manage and incorporate more specific studies to identify impacts to ungulates and their habitats in areas subject to resource extraction activities. Increased monitoring will help management agencies avoid overharvesting ungulates where access has increased due to energy or other developments.

ACKNOWLEDGMENTS

Our research was possible through the efforts of the many WGFD biologists who collected mule deer and pronghorn herd demographic data included in our 33-year analysis. We especially acknowledge D. Legg, University of Wyoming, for his critical assistance with statistical analyses. M. Kauffman, R. Coupal, and P. Stahl from the University of Wyoming all provided helpful insights in regard to study design and analyses. We also thank J. Emmerich, S. Smith, and T. Gerhardt from WGFD for their insights. B. Brokling and K. Rogers processed spatial data for use in analyses. Our research was supported by WGFD Grant Number 0020011.

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Table 1. Number of parameters (K), change in AIC value from the top model (ΔAIC), log-likelihood (LL), and Akaike weights (ω) for models (a) affecting success (%) of mule deer harvest, and (b) model-averaged parameter estimates and confidence intervals for parameters that influenced mule deer hunter harvest success (%) in Wyoming, USA, 1980–2012.

(a)

Model for Hunter Success (%)	K	Δ AIC	LL	Weights ω
Effort + Hunters + Well Pads	6	0	669.78	0.51
Effort + Hunters + Public + Well Pads	7	2.03	669.78	0.19
Effort + Hunters + Precipitation + Well Pads	7	2.04	669.78	0.19

(b)

		95% CI	
Parameter	Estimate	Lower	Upper
Effort	-0.268	-0.294	-0.243
Effort^2	0.025	0.022	0.029
Hunters	-0.004	-0.012	0.003
Precipitation	0.023	-0.640	0.686
Public	-0.077	-1.224	1.071
Well Pads	0.025	0.008	0.042

Table 2. Number of parameters (K), change in AIC value from the top model (ΔAIC), log-likelihood (LL), and Akaike weight (ω) results of variables affecting (a) hunter success (%) of pronghorn harvest, and (b) model-averaged parameter estimates and confidence intervals for parameters that influenced pronghorn hunter harvest success (%) in Wyoming, USA, 1980–2012.

(a)

Model for Success (%)	K	Δ AIC	LL	Weights ω
Effort + Hunters + Well Pads	6	0	1491.32	0.37
Effort + Hunters	5	1.67	1489.48	0.16
Effort + Hunters + Public + Well Pads	7	1.95	1491.37	0.14
Effort + Hunters + Precipitation + Well Pads	7	2.03	1491.33	0.13
Effort + Hunters + Precipitation	6	3.67	1489.49	0.06
Effort + Hunters + Public	6	3.68	1489.49	0.06
Effort + Hunters + Precipitation + Public + Well Pads	8	3.98	1491.37	0.05

(b)

Parameter	Estimate	95% CI	
		Lower	Upper
Effort	-0.331	-0.382	-0.280
Effort^2	0.002	0.001	0.003
Hunters	-0.003	-0.010	0.005
Precipitation	-0.009	-0.357	0.338
Public	0.027	-0.210	0.264
Well Pads	0.008	-0.000	0.016

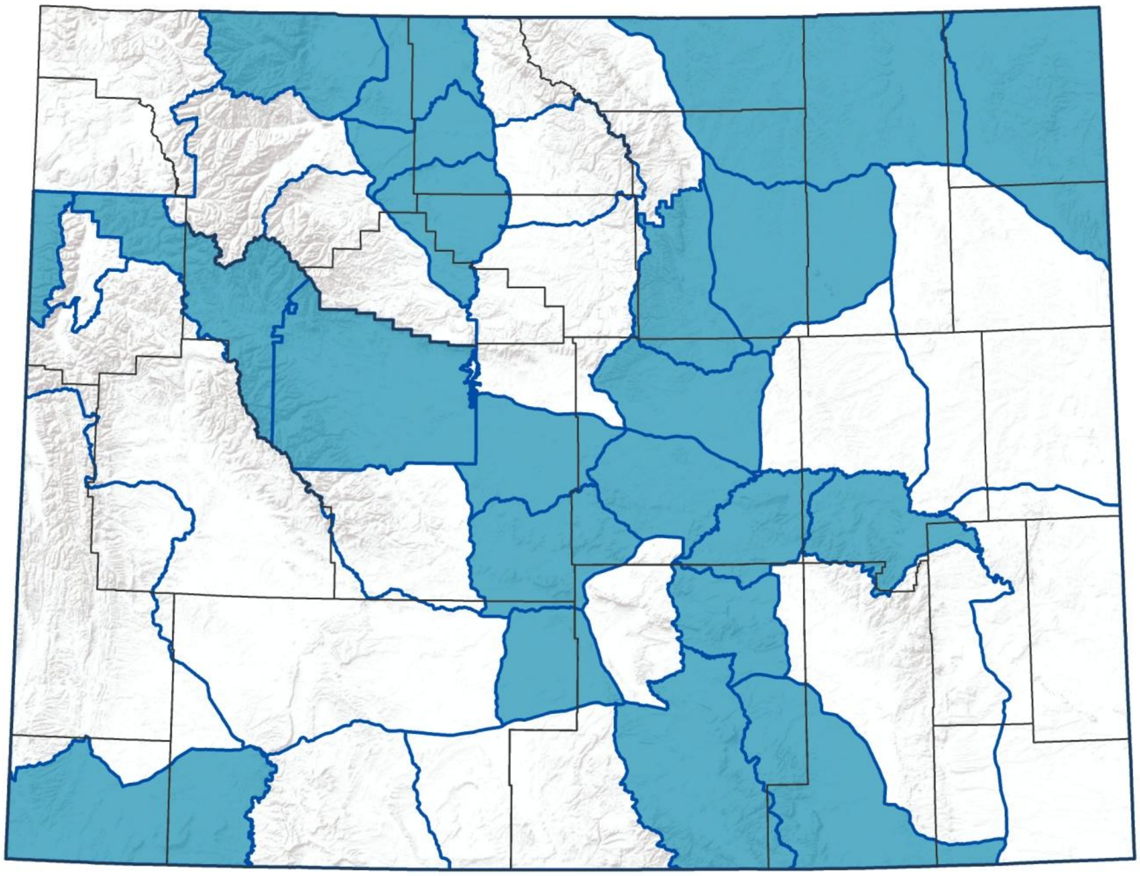

Figure 1. Location of the 22 Wyoming Game and Fish Department Mule Deer Herd Units (shaded in blue) evaluated in Wyoming, USA, 1980–2012.

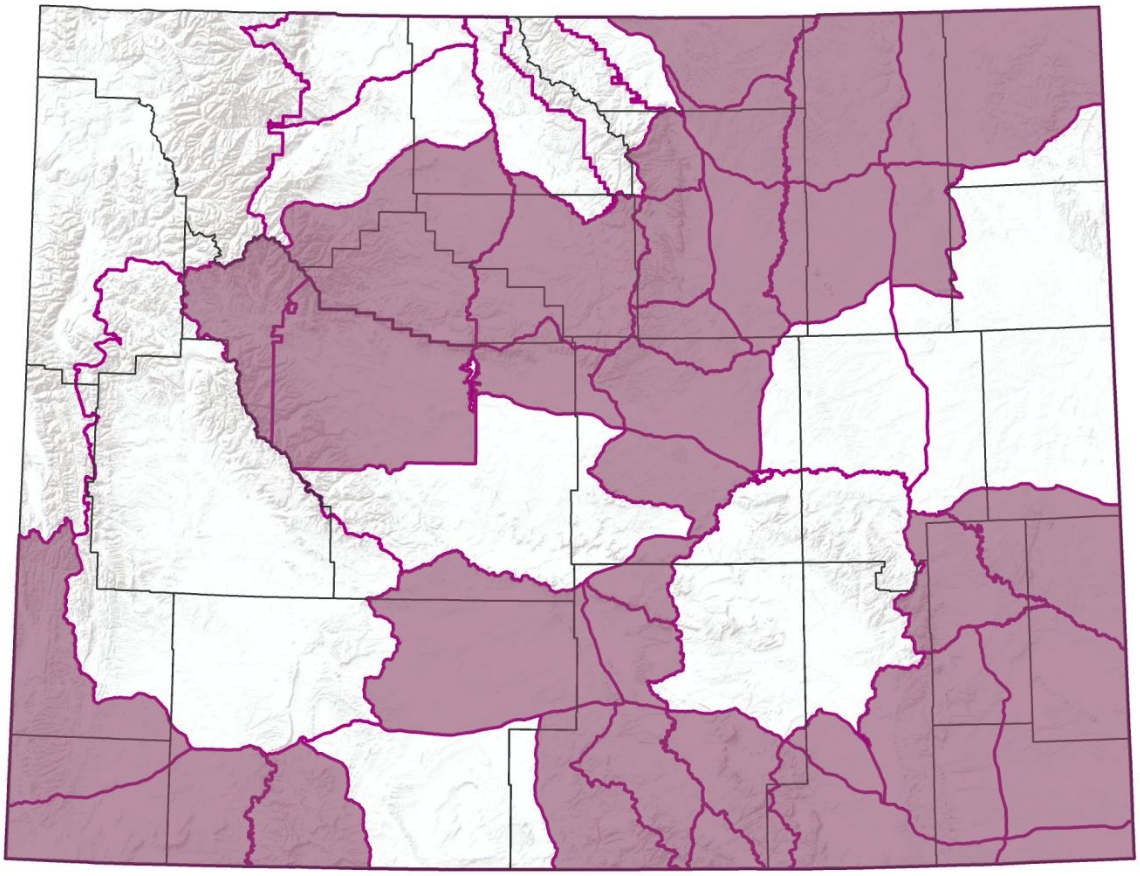

Figure 2. Location of 34 pronghorn Herd Units (shaded in red) evaluated in Wyoming, USA, 1980–2012.

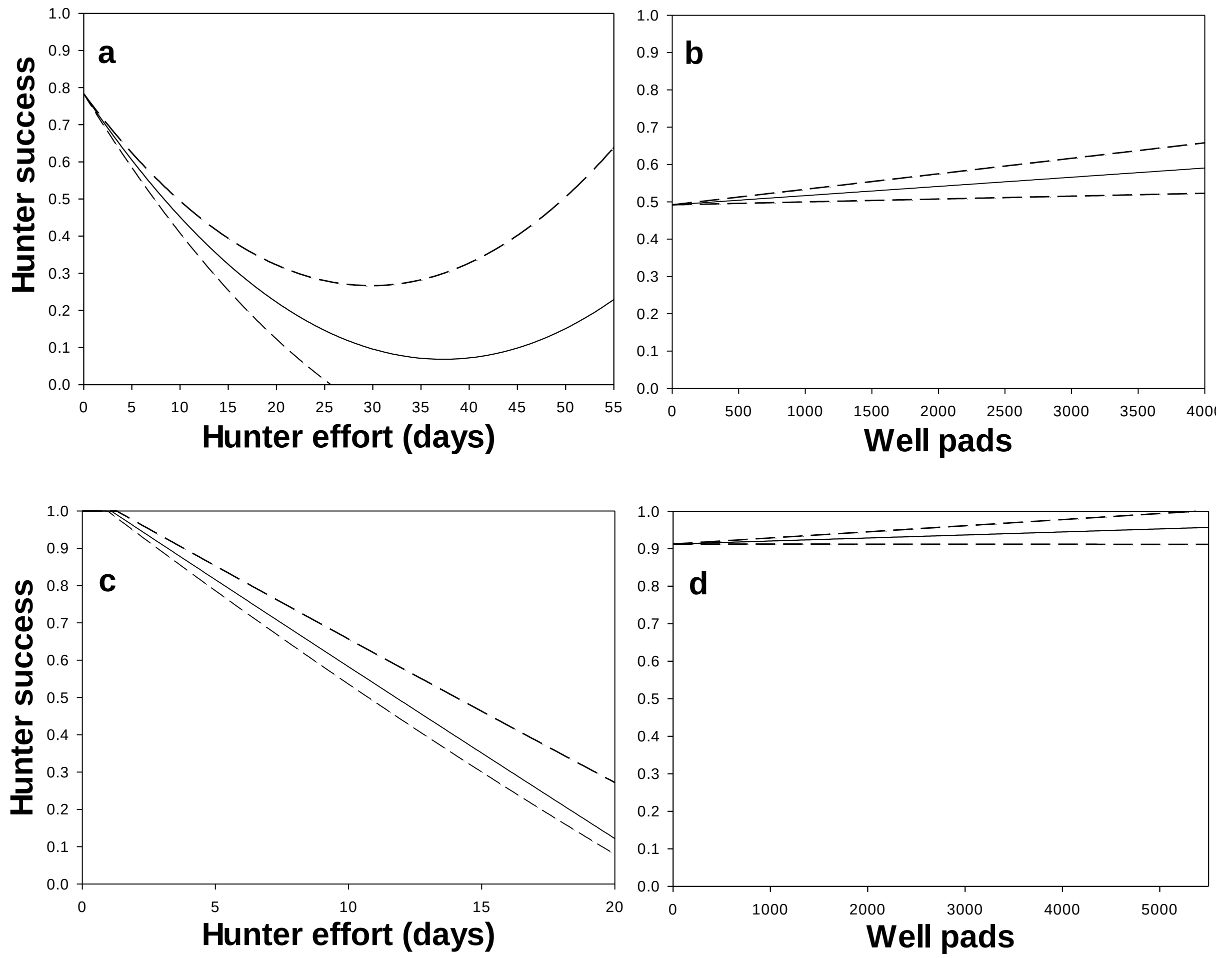

Figure 3. a. Hunter success in response to hunter effort (days) in Wyoming Game and Fish Department mule deer Herd Units, 1980–2012. b. Hunter success in response to well pads in Wyoming Game and Fish Department mule deer Herd Units, 1980–2012. c. Hunter success in response to hunter effort (days) in Wyoming Game and Fish Department pronghorn Herd Units, 1980–2012. d. Hunter success in response to pronghorn hunters per Herd Unit, 1980–2012. Dashed lines are 95% confidence intervals.

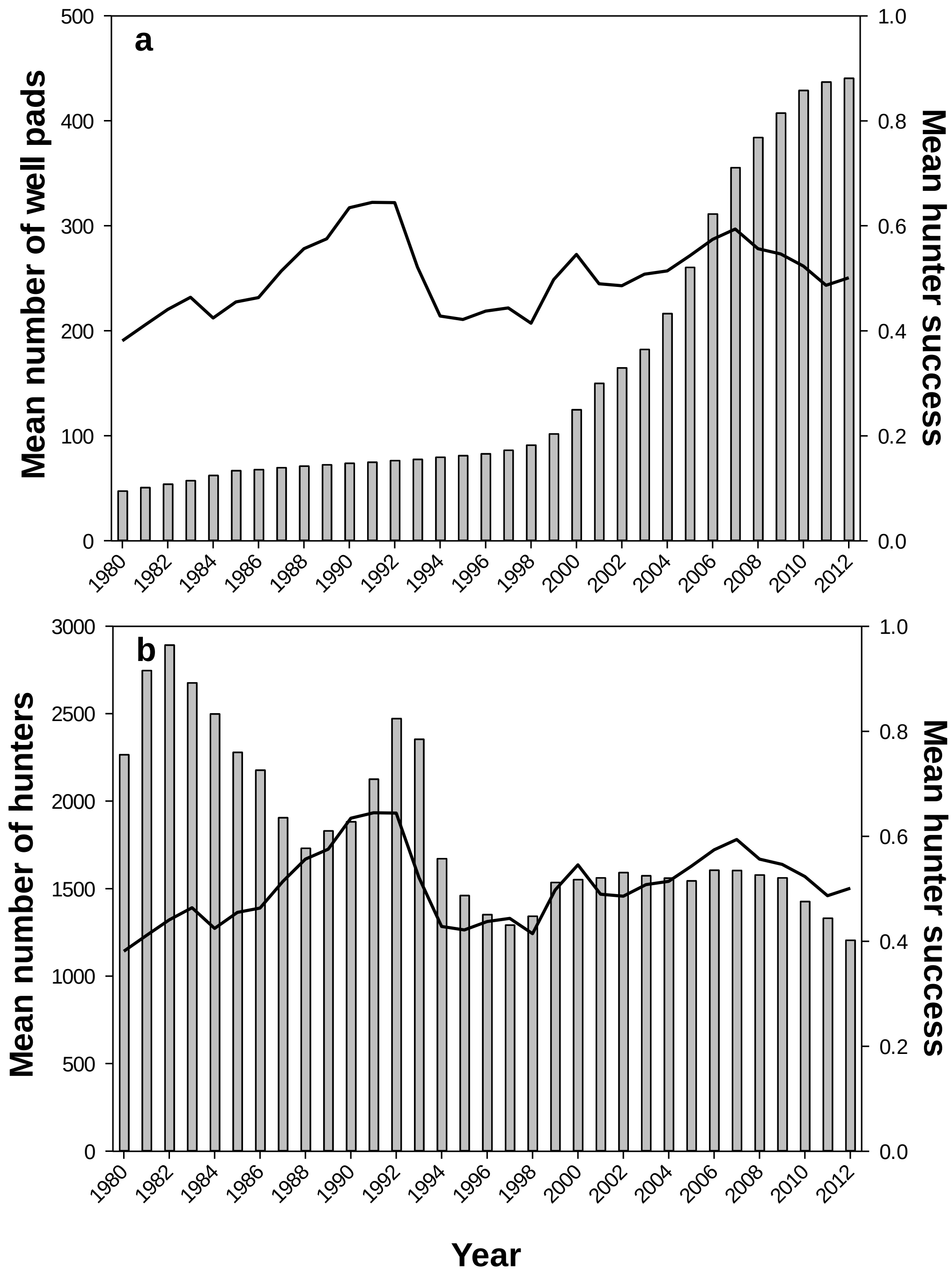

Figure 4. a. Mean well pads and mean mule deer hunter success (%), 1980–2012. b. Mean mule deer hunters per Herd Unit and mean hunter success (%), 1980–2012. Data reported from Wyoming Game and Fish Department mule deer Herd Units.

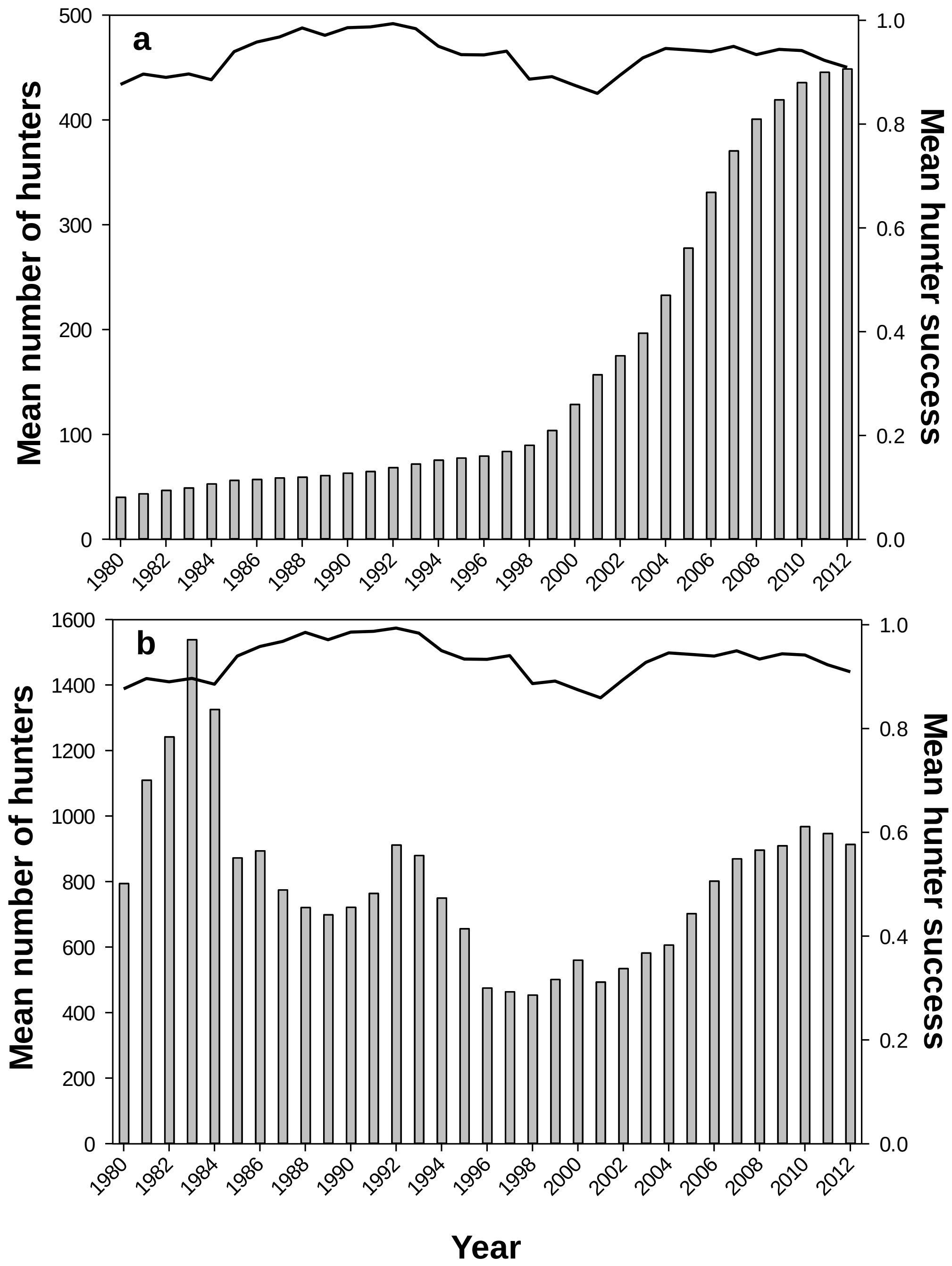

Figure 5. a. Mean well pads and pronghorn hunter success (%), 1980–2012. b. Mean pronghorn hunters per Herd Unit and hunter success (%), 1980–2012. Data reported from Wyoming Game and Fish Department pronghorn Herd Units.