Literature Review and Synthesis on the Effects of Residential Development on Ungulate Winter Range in the Rocky Mountain West

Jean Polfus

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Executive Summary

In the past 40 years rural residential development has increased dramatically in the valley bottoms and mountain foothills of the Rocky Mountain West. Development has diverse impacts on wildlife including altered ecological community composition and biotic interactions, fragmentation of natural landcover and the establishment of source sink dynamics. All of these mediators have been linked to modified species behavior, such as avoidance of areas near development and human activity, interrupted dispersal and movement patterns, restricted distributions and population declines. Wildlife persistence is unmistakably dependent on available habitat – habitat which is quickly being compromised by extensive human development across the American West.

During winter ungulates must select resources to sustain a positive energy balance, minimize energetic costs and reduce predation risk across broad temporal and spatial scales. In general, ungulate winter range includes low-elevation valley bottoms and mountain foothills composed of a mixture of private and public lands that have low snow cover and high solar radiation. Typically, agricultural or ranch land is the first to be converted into residential spaces across the West. This focuses most new residential growth in productive regions that support high species biodiversity. Thus, high quality ungulate winter range and new developments are intersecting at increasing rates. Roads and subdivisions near and in winter range affect ungulate populations through multiple behavioral, physiological, population and ecological community processes.

I reviewed > 80 peer-reviewed articles, theses, dissertations, reports and professional papers on the effects of human disturbance and residential development on five ungulate species: white-tailed deer, mule deer, elk, American pronghorn and bighorn sheep. Unfortunately, very few studies have focused exclusively on the effects of residential development on ungulates (n=22), thus, I also emphasize key studies on the effects of human activity, roads and industrial development on ungulate populations. In each section I detail key characteristics of winter range and highlight various impacts of development from overt behavioral reactions to population-level responses. Problems associated with habituation, migration, disease and predation are also reviewed.

White-tailed deer populations have expanded in the last century and display high adaptability to human activity. Most studies on white-tailed deer response to residential development have occurred in the eastern or midwestern United States. These studies suggest that deer often select high quality forage near residential structures and benefit from reduced predation rates and a lack of hunting by humans in close proximity to developments. White-tailed deer may display greater avoidance of human disturbance during sensitive biological seasons. In some situations, white-tailed deer habitat use has declined with increasing housing densities. Habituated white-tailed deer impact humans through the spread of diseases, increased deer-vehicle collisions, attacks on humans and alterations to plant structure and community composition. Human attitudes and perceptions of white-tailed deer in urban environments can limit wildlife management options such as hunting. Care should be taken to fully understand the effects of development on local populations before critical habitat is lost.

Mule deer populations in the West have declined in recent decades. Though research has not isolated the confounding factors involved in the declines, it is probable that residential development has played a significant role. Mule deer are known to display behavioral escape responses such as avoidance, decreased flight initiation distances and other behavioral reactions to human activity and recreation. Studies indicate that mule deer often avoid roads and industrial infrastructure. In some cases, avoidance of human disturbance can increase energy expenditure and may impact individual survival during the winter. Because mule deer utilize flexible migration behaviors to maximize resources and decrease predation pressure, development in migration corridors can have significant consequences. Like white-tailed deer, mule deer can also become habituated to urban areas. Abundant deer populations pose a threat to human safety, cause property damage and can generate concerns for animal welfare. Future research is needed to determine how predation, disease and residential developments may interact to influence mule deer populations.

Elk initially respond to human disturbance with increased vigilance, flight responses and behavioral avoidance, all of which have the potential to increase winter energy expenditure. In northern climates, decreases in energy reserves during winter can lower survival. Therefore, development has the potential to lead to severe population level declines in elk. Unfortunately, very few studies have directly examined the population-level consequences of human development on elk. However, large developments, such as ski areas, can alter elk distributions during sensitive periods such as fawning, leading to decreased reproductive success. Without direct negative pressure from humans, elk can and will habituate to human activity. Habituated elk are associated with crop depredation, overgrazing, property damage, injury to humans, disease transmission and an eventual decline in migratory behavior. Elk also react to pressure from hunting by humans by moving to areas with hunting restrictions such as private lands. As hunter-friendly ranches are increasingly transformed into subdivisions, more land is available as a refuge for elk during the hunting season. This reduces the ability of managers to control elk populations, further escalating problems with habituation.

No studies have specifically examined the impact of residential development on American pronghorn behavior or demography. However, research on the impacts of human disturbance on pronghorn indicates that pronghorn increase vigilance, flight responses and behavioral avoidance near human activity. Pronghorn need large contiguous areas with relatively few physical barriers to complete seasonal migrations. Energy development, transportation infrastructure, fencing and rural residential development are all threats to pronghorn migration. Mitigating the effects of residential development in critical migration bottlenecks should receive priority conservation. Pronghorn can habituate to certain levels of disturbance, especially when not hunted or harassed. During severe winters pronghorn may select agricultural lands which can reduce or eliminate migratory behavior. Resident habituated pronghorn can deplete agricultural crops and may be at higher risk for vehicle collisions. In general, pronghorn persistence is dependent on large-scale, multi-jurisdictional initiatives to protect critical migration corridors and winter ranges.

Similar to pronghorn, no specific research has been conducted on the effects of residential development on bighorn sheep behavior or demography. Historic declines in bighorn sheep are likely due to expansion of urban development, resource extraction, disease, competition with domestic livestock and habitat fragmentation; though no cause and effect studies documented the declines. Mountain sheep are highly vigilant and exhibit a number of overt behavioral reactions in response to human disturbance. Where human development intersects sheep range, roads may act as a barrier to movement, especially when highways bisect migration routes or corridors to important seasonal mineral lick sites. Aircraft overflights can increase movement rates, heart rates and interrupt foraging and resting behaviors. Disease and parasite levels have also increased following human disturbance. Evidence of habituation to temporally and spatially predictable human activity has been documented in certain situations. Protection and maintenance of mountain sheep habitat is essential to prevent extirpations similar to those observed in the past century.

In summary, most ungulates exhibit short-term behavioral reactions in response to human disturbance. However, very few studies have linked these responses to population-level consequences. These inferences are needed to evaluate the effectiveness of management strategies, understand and predict the impacts of development and monitor regulatory requirements. Several recent long term monitoring projects on the effects of energy development on ungulates suggest that demographic impacts may take many years to detect. Compensatory reproduction and resilience in adult age-cohorts create time lags between disturbance events and the eventual long-term impact on the population. Thus, there is a pressing need for long-term cumulative effects studies that can clarify the mechanisms driving changes in abundance and distribution.

Recently, ‘conservation development’ has been proposed as an alternative to traditional development patterns. By clustering homes in a small area, conservation development reduces the overall footprint by minimizing the influence of each house on the ecosystem. Thus, large-scale impacts on open spaces and agricultural lands can be mitigated. However, there is growing concern that these strategies may neglect important high quality wildlife habitat. New research indicates that the configuration of development (i.e., where clustered development occurs on the landscape) is at least as important, if not more important, than simply conserving open space.

Land use guidelines can help facilitate the development of policies and regulations needed to guide decisions on how to design developments and regulate their influence on wildlife. Guidelines are often specific to ecological and political scales. At the smaller site scale, guidelines suggest buffering development, reducing exotic species, reducing fencing and other barriers to movement, reducing noise and light disturbance, controlling domestic pets, maintaining connected patches of undeveloped land and assessing site level habitat conditions. At the larger landscape scale, collaboration between governments, local jurisdictions, NGOs and private interests are needed to maintain large intact patches of unfragmented habitat. To protect winter range development should be clustered in areas near existing development to leave as much high quality winter range undeveloped as possible.

As the West faces continuing pressure to develop ungulate winter range, policies and regulations that incorporate scientific research, ecological principles and land use planning guidelines are essential for successful conservation of important ungulate habitat and migration corridors. This requires ecologists and wildlife managers to engage with land use planners to ensure that pertinent research directs large-scale development patterns. To date, no studies have rigorously analyzed the population-level impacts of residential development on ungulates. Though this lack of definitive research can sometimes delay the implementation of policies and regulations, planners must proceed on the basis of the most pertinent scientific research as well as the professional opinion of planners and wildlife managers. As new information is acquired, policies should be modified accordingly. Adaptive management is one possible avenue towards evaluating the impact of residential development on ungulate winter range.

Introduction

Human influence on natural systems is drastically increasing as the world population grows and the pace of industrialization and consumption progress. The total land area impacted by human activities is projected to increase to 50-90% worldwide by 2050 (UNEP 2001). The accelerating rate of habitat loss is the primary cause of wildlife population decline and extinction (Fahrig 1997, Myers et al. 2000, Brooks et al. 2002). Human developments and activity can impact wildlife through changes in behavior to decreased survival or fecundity and large-scale regional extinctions (Ceballos and Ehrlich 2002). The term *effect* refers to the change in the environment caused by human activity, while the term *impact* represents the consequences of these changes on wildlife (Wathern 1990, Johnson and St-Laurent 2011). While most human development will have an effect on an ecosystem, the spatial and temporal impacts on wildlife may vary by season, disturbance type, species and a range of other environmental factors (Johnson and St-Laurent 2011). The expansion of the human population and, in particular, the associated demand for housing space, is and will continue to be a challenge to wildlife management and conservation with unpredictable and unprecedented impacts on natural systems (Liu et al. 2003).

Historically, settlement of the mountainous regions of the American West was constrained to valley bottoms by topography and water availability. As land was bought and sold in the early 1900s, a general pattern emerged with public lands at high elevations and private lands at lower elevations (Knight et al. 1995, Gude et al. 2006). Because of the extreme winter conditions associated with high elevations, valley bottoms and mountain foothills are important winter habitat for many species, including ungulates (Safford 2003). Many ungulates lose body mass over the winter due to increased energetic costs of gestation for females (Pekins et al. 1998), movement in snow (Parker et al. 1984, Fancy and White 1987), and starvation due to poor winter nutrition (Festa-Bianchet 1989, Post and Klein 1999, Creel and Creel 2009, Parker et al. 2009). Fine scale winter habitat preferences vary between species, but ungulates generally prefer low elevation areas composed of a mixture of large tract ranch land and low elevation public land that have low snow cover and high solar radiation (Anderson et al. 2005, D'Eon and Serrouya 2005, Christianson and Creel 2007, Klaver et al. 2008).


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In the past 40 years the human population and rural residential development have increased dramatically in valley bottoms and low elevation foothills, especially in the highly scenic areas near national parks that contain the largest densities of ungulates (Gude et al. 2006). The rate of land conversion into residential development often exceeds the rate of human population growth (Fulton et al. 2001). Development that occurs along the urban-rural gradient beyond urban and suburban areas has been termed exurban (Table 2., Nelson 1992). It is characterized by low-density vehicle-dependent residential development, segregated land uses, poor pedestrian access to services and a lack of community-based shared spaces (Johnson 2001, Ewing et al. 2005). Exurban sprawl can be especially detrimental because it results in the loss of more land to accommodate fewer people. The conditions that make winter range preferable to ungulates, including relatively low snowfall, high solar radiation and proximity to summer range, are often also desirable to humans. The rising rate of exurban development in the Rocky Mountain West means that high quality ungulate winter range and new development will intersect at increasing rates. Roads and subdivisions near and in winter range affect ungulate herds through multiple behavioral and demographic responses and at the same time reduce management options. The high rate of land use change is projected to continue, making local land use management plans especially important to preserving important ungulate habitat (Gude et al. 2007).

The direct and indirect effects of exurban development on ungulate winter range vary by region, ungulate and predator species, specific habitat type and development structures. This review will explore the effects of land use change, especially residential development at exurban densities, on the following ungulates of the Rocky Mountain West: white-tailed deer (*Odocoileus virginianus*), mule deer (*Odocoileus hemionus*), elk (*Cervus elaphus*), American pronghorn (*Antilocapra antilocapra*) and bighorn sheep (*Ovis canadensis*). To support efforts by Montana Fish Wildlife and Parks to offer guidance to local governments and land developers on proposed subdivisions and future rural development, I will also review papers describing the integration of ecological principles into land use planning and how they can be applied to the development planning on or near ungulate winter range. In summary, the objectives of this literature review are to:

- Review the impacts of land use change, especially residential development, on ungulates in the Rocky Mountain West,
- Review the history and status of land use change in the Rocky Mountain West, and its implications to ungulate winter range,
- Summarize land use and growth management policies that affect ungulates,
- Review weaknesses and limitations in the current literature available, and
- Recommend guidelines for future research.

Methods and Scope

I conducted a literature review of the effects of residential development on five focal species using a variety of electronic resources including: ISI Web of Knowledge, Zoological Record, CSA Biological Sciences, CSA Illustrata: Natural Sciences, Google Scholar, and Biological Abstracts. I used a combination of the following keywords: ungulates, exurban development, residential development, mule deer, white-tailed deer, pronghorn, elk, bighorn sheep, energy development, roads, habitat degradation, human impact, habitat suitability, habitat quality, home range, survival, recruitment and resource selection. I focused on studies that incorporated specific responses of ungulates to human land use change including residential development, industrial development, roads and other impacts. I also included literature reviews, grey literature reports, theses and dissertations that explored the effects of human development on wildlife and land use policies in the West including suggested guidelines towards sustainable development. Articles were mined for references that were relevant and that did not show up in the search criteria.

To summarize the literature I recorded information on the following categories for each research article that was relevant to ungulates response to human development: peer review status, sample size, study area location, study area size (km^2), study duration (years study occurred), type of development, study design (review, modeling, experimental, observational, telemetry, comparative, survey, before/after), housing buffer, estimated minimum patch size, general methods, general results and conclusions and management recommendations. These summaries can be found at the end of each species summary section in this report. Other pertinent literature on ungulates is summarized in Appendix A. Though the list of articles is extensive, it is likely that some studies may have been overlooked because they were grey literature, rarely cited or did not match the search criteria. Not every article reviewed in the text is included in the summary tables.

Results

I reviewed over 100 articles on the impacts of residential development on wildlife. Not all studies reviewed were summarized in the tables at the end of each species section. Approximately 80 studies were directly related to the effects of human development on ungulates. Only 22 specifically examined residential development and its influences on the five focal species (Table 1). Most studies (n=55) were observational studies that inferred the impact of development by correlating behavioral responses to human developments. This is generally the weakest study design and makes determining cause and effect difficult (Hebblewhite 2008). Comparative studies (n=7), examined responses before and during/after development, or between control and treatment areas. Experimental designs (n=8) included controlled situations in which a treatment was applied to individuals or a population and results were compared to controls.

Table 1. Summary of pertinent literature reviewed by species and human disturbance type (some studies included more than one species and more than one development type).

Species	Total	Peer Review	Residential	Recreation	Energy Development	Roads	Other
White-tailed deer	14	10	14	-	-	-	-
Mule deer	19	14	5	3	5	3	3
Elk	17	12	4	5	-	5	3
Pronghorn	14	5	1	1	4	1	2
Mt. Sheep	16	12	-	6	3	-	5
Total	**80**	**53**	**24** (22 total)	**15**	**12**	**9**	**13**

Geographically, all but one study on the effects of residential development on white-tailed deer occurred in the midwestern and eastern United States (Figure 1). Studies on the effects of aircraft on bighorn sheep all occurred in the dessert southwest, where Department of Defense lands exist. Most elk studies occurred along the Rocky Mountains. Studies on energy development cluster in southwestern Wyoming and southern Alberta, Canada.

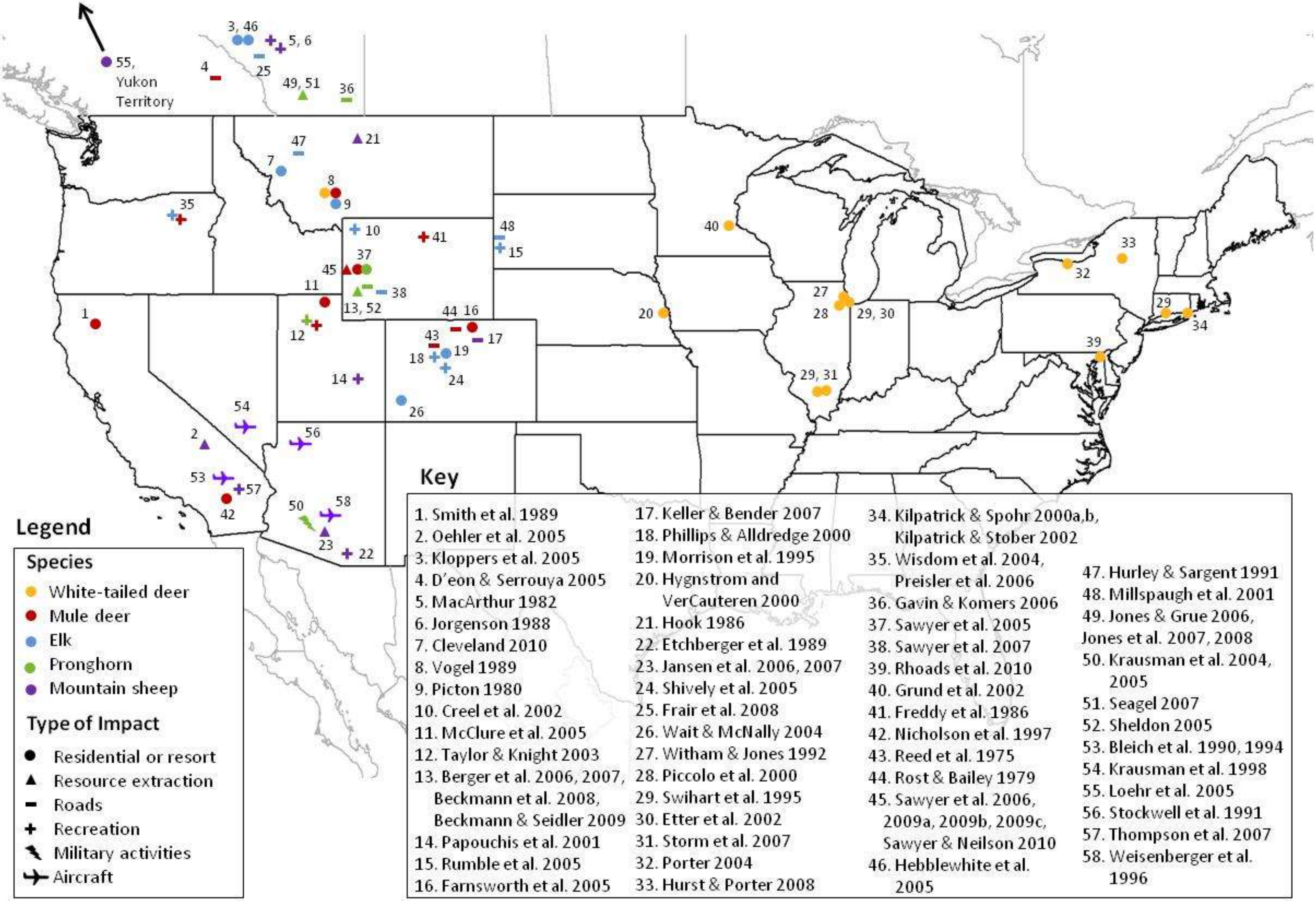


Figure 1. Location of studies on the effects of human development and activity on ungulates.

Land Use Change

The expansion of human development into intact ecosystems is inevitable as land is converted to accommodate the increasing human population (McKinney 2002, Foley et al. 2005). In 2010, the U.S. census indicated that the population of the Western U.S. grew dramatically, resulting in a 13.8% increase from 2000. Montana's population increased by 9.7%, while Idaho, Wyoming, Utah and Colorado increased by 21.1%, 13.1%, 23.8%, and 16.9% respectively, all well above the national average of 8.8% (Figure 2., http://2010.census.gov). The influx of humans in the West since 1910, mostly comprised of European settlers, has had diverse ecological and economic consequences, from the forced removal of Native American people from their traditional territories in the late 1800s to the current demand for increased energy consumption and natural resource extraction. Economic growth often competes with wildlife conservation because of the conflicting goals of sustainable management and production of consumption goods and services (Czech 2000). However, there is a growing appreciation for green infrastructure strategies that protect critical wildlife habitats while at the same time supporting education and healthcare services, recreation, tourism and sustainable local economies (Chambers et al. 2010). As the West faces future economic, ecological and demographic transitions collaboration between governments, local jurisdictions, NGOs and private interests will be required to promote sustainable development.

Globally, the increase in resource exploration, mines, power lines, pipelines, utilities, hydroelectric plants and dams has progressively altered the distribution and abundance of species. Extensive studies, books and reviews have documented the impact that conspicuous land use change as a result of resource extraction, logging and energy development has had on wildlife (UNEP 2001, Hebblewhite 2008, Vistnes and Nellemann 2008, Naugle 2011), and a comprehensive review of this topic is beyond the scope of this paper. Much less attention has been given to the impacts residential structures, offices and shopping centers have on the habitat and population dynamics of wildlife (but see Glennon and Kretser 2005, Hansen et al. 2005, Krausman et al. 2011). Growing evidence indicates that while houses may appear to have a smaller footprint than industrial infrastructure, the combination of the reckless pace of residential development and the lack of comprehensive and enforceable land use policies ensures that residential development in the West will have considerable impacts on wildlife (Hansen et al. 2005).

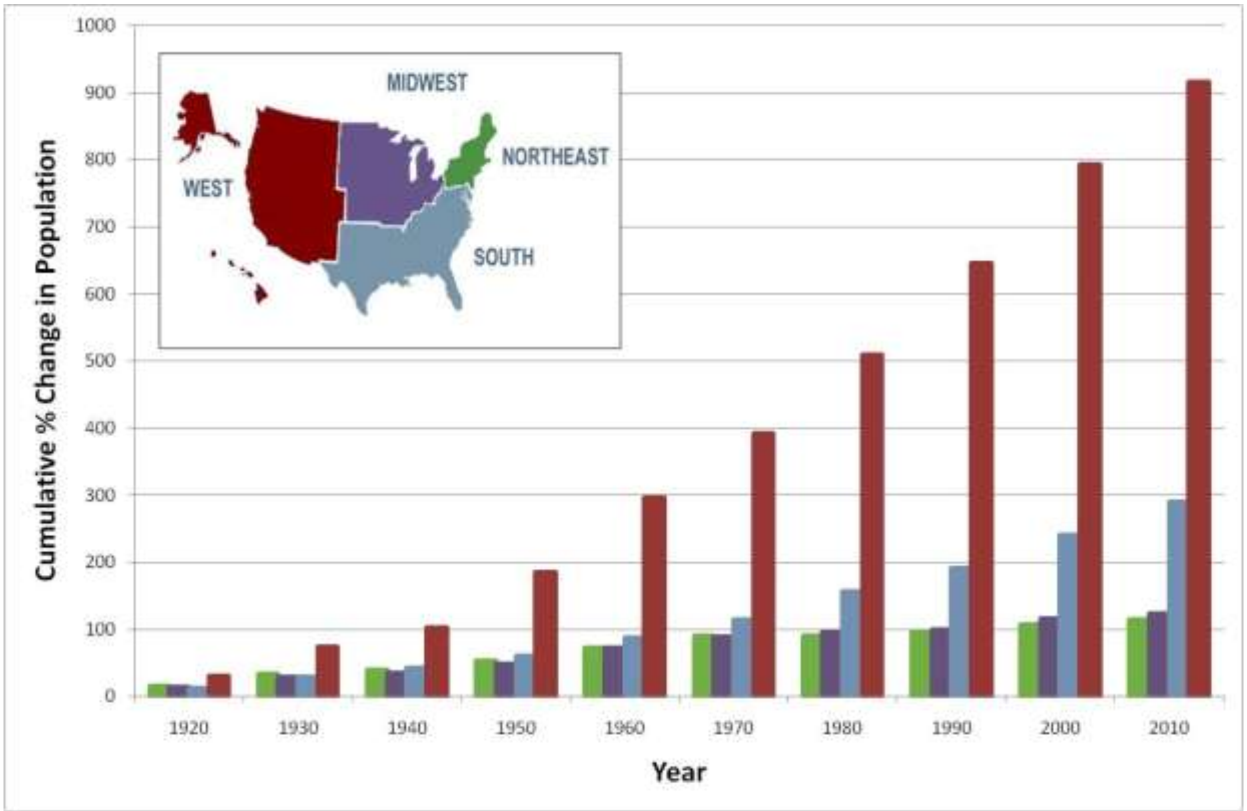


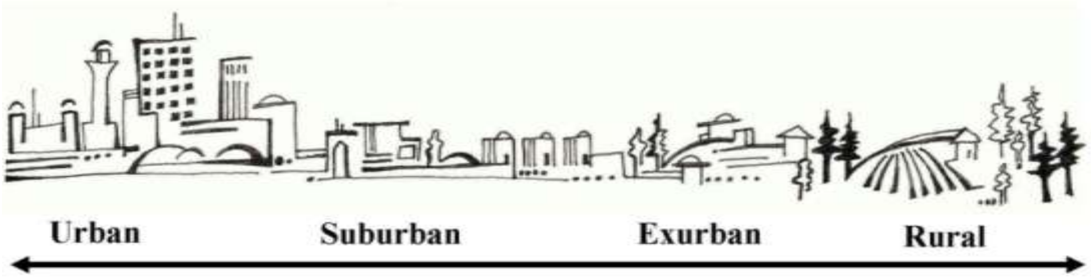
Figure 2. Cumulative change in U.S. population from census data by regions from 1910 to 2010. Red bars indicate that the West has consistently experienced the highest rates of population growth.

Exurban Development

For the purposes of this paper, the term exurban is used to describe development located in areas along the urban-rural gradient that are beyond the reach of urban public facilities and services. Beginning in the 1970s, growth of rural areas began to exceed growth of metropolitan regions. By 2000, over 25% (1.39 million km^2) of the conterminous U.S. was occupied at exurban densities (1 unit per 1 to 40 acres), resulting in extensive impacts on agricultural lands, forests and range lands (Brown et al. 2005). Some estimates suggest that exurbia is home to approximately 37% of the U.S. population (Travis 2007) and encompasses an area 7 times larger than urban and suburban areas combined (Theobald 2005). Generally, ‘exurban’ is characterized by large lot sizes, low overall housing densities and close proximity to rural or undeveloped lands (Table 2). Because exurban densities are so low, each new residential development has a disproportionately large effect on the surrounding area (Leinwand et al. 2010). Some authors include urban fringe development as exurban development, especially in areas where physical commuting can still occur, although telecommuting has increased the distance from major metropolitan areas (Nelson 1992, Hansen et al. 2005). Exurban development is unique because it is often the first major development on lands that were previously natural, undeveloped or agricultural (Radeloff et al. 2005). Thus, surrounding habitat patches remain connected and are often dominated by native vegetation complexes (Odell and Knight 2001, Brown et al. 2005).

Unfortunately, there is a lack of consensus in the literature on a consistent definition of exurban densities (Arendt 1997). Terminology varies between land use planners, local governments, developers, biologists and community members and descriptions range from the number of structures per square kilometer to density based on human population or the number of acres per housing unit. Because roads may influence habitat differently than residential units that include lawns, pavement and ranging domestic pets, there is a need to refine descriptions of developments by specific types or classes (Theobald et al. 2005). To further complicate the situation, available data on housing densities, road type, traffic volumes and human activity levels can vary between districts, counties, planning regions and states. This lack of consistency makes it challenging to compare management plans and development policies between regions. However, advances in remote sensing, mapping capabilities and GIS applications have the potential to bring consistency to the field (Travis et al. 2005). If the overall goal of management is to understand how heterogeneous resources affect wildlife population viability, then the functional properties of developments must be examined at multiple spatial and temporal scales (see section on Impacts of Human Development on Ungulates, Theobald et al. 2005). From a wildlife biology perspective, there is a need to understand the scale of ecological thresholds that define important demographic consequences to wildlife species. As McIntyre and Hobbs (1999) note, “how an organism experiences landscape alteration, is of more significance in conservation biology than the human perspective.”

Table 2. Summary of number of acres per housing unit across the urban – rural gradient (diagram by J. Polfus).



Author	**number of acres per housing unit**			
Hansen et al. 2005			9.9-41.2 acres	
Brown et al. 2005	1 acre		1-40 acres	> 40 acres
Theobald 2004	1 acre	1 to 10 acres	10-40 acres	> 41 acres
Clark et al. 2005			1.65-16.5 acres (medium exurbia)	> 165 acres
Glennon & Kretser 2005			5-40 acres	
Lenth et al 2006			39.5 acres	
Daniels 1999			5-10 acres	

Spatial Distribution of Private and Public Lands

The recent drivers of exurban development are nested within a complex history of land use change in the Western U.S. Understanding the factors that influence land use change is necessary to make informed decisions about future trends and the appropriateness of various management techniques (Brown et al. 2005). Well before colonial influence, the American landscape was modified by Native American people to ensure essential resources remained present (Czech 1995, Krech 1999). Thus, it is important to understand the idealistic perspective of the term "natural" or "wild" when referring to conditions prior to European settlement (Krech 2005). In the early 1900s, the boom-bust markets for metal, timber and cattle defined the political, social and ecological geography of the American West (Limerick et al. 2002). In addition to the inherently unstable natural resource-based economies in the region, land speculation was a significant market that created a land use regime based on private property (Travis 2007).

Almost half the land base in the Western U.S. is federally owned and will not be modified by extensive agricultural, residential and commercial uses (Figure 3). While roads, mines, energy development, forestry, campgrounds and lodges can occur on federal lands, the sprawl of metropolitan areas and exurban development will be limited to private lands. This, more than any other factor, makes the dynamics of land use in the West unique when compared to the rest of the country (Travis 2007). Travis (2007) points out that the "relationships between developed and undeveloped land, and between development and topography, play an important role in shaping sense of place in the American West." Public lands, largely composed of Forest Service (USFS) and Bureau of Land Management (BLM) lands (but also including state lands) occur largely at higher elevations and desert basins while private lands dominate fertile river valley bottoms and mountain foothills with the most productive soils, the greatest species diversity (Scott et al. 2001, Ewing et al. 2005) and much of the West's ungulate winter range. The interactions between private and public lands influence the spatial pattern of land use change, and can have consequences on species, such as ungulates, that utilize essential seasonal ranges.

Of the private lands available in the West, almost one fifth have been developed for residential, industrial or commercial use (Travis 2007). While population growth may be the ultimate driver of the increasing rate of exurban development, a complex suite of factors determine where and why exurban growth occurs. Some researchers have suggested that the settlement of the West has been shaped by three stages of growth: natural resource constraints, transportation expansion and the pursuit of natural amenities (Huston 2005, Gude et al. 2006). Currently, the resource-based economies of ranching, farming, mining and logging are being replaced by private sector jobs that support tourism, recreation, retirement and second homes (Shumway and Otterstrom 2001). This economic transition is being fueled by amenity migrants who value environmental quality more than economic opportunities (Nelson 2003). The attraction of small town life, areas of high social and scenic amenities, recreational activities and safe communities are hastening the growth of exurban regions in the West by attracting highly skilled professionals and entrepreneurs as well as retirees and tourists (McGranahan 1999, Rudzitis 1999, Rasker and Hansen 2000). Interestingly, these new residents are driving employment opportunities and economic activity in rural areas rather than the other way around, further perpetuating the evolution of the “New West” (Shumway and Otterstrom 2001). The changing demographic makeup also brings about disparate perceptions of wildlife and the environmental attitudes which can lead to new conflicts over the fate of the New West (Peterson et al. 2008).

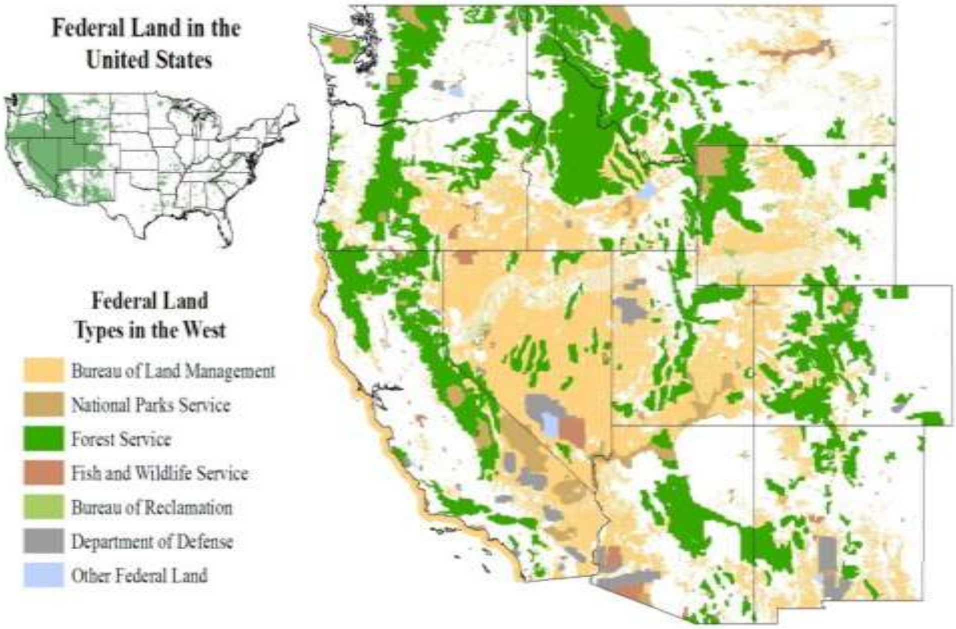


Figure 3. Distribution of public and private (white areas) lands in the West (data from the National Atlas of the United States 2006).

Typically, agricultural or ranch land is the first to be converted to exurban residential spaces. This focuses most new growth in low elevation valley bottoms (Knight et al. 1995, Gude et al. 2006). Further, the proximity of private land to national parks or other wilderness lands, biologically diverse riparian areas, lakes and productive farmlands increases the probability of development (Gude et al. 2006, Jarvis 2008). The transfer of ranches from traditional owners to amenity buyers has altered management models and goals. Some large lots are fragmented into many small private parcels which complicates issues related to access, rights of way, water rights, liability and public relations (Knight et al. 1995). Other land is sold intact to non-traditional owners who manage not for livestock, but a variety of amenity-related pursuits or conservation initiatives (Gosnell et al. 2006, Travis 2007). Tension can arise between new migrants and long-time locals on issues such as land use regulations, predator abundance and irrigation practices. Complicating the situation, in some areas private lands are used by ungulates as a refuge during hunting seasons (Burcham et al. 1999). Traditional agreements with private landowners to manage these herds have become more complicated (Haggerty and Travis 2006). Hunting has become less of a viable management tool due to increased restricted areas surrounding new exurban development (Harden et al. 2005, Haggerty and Travis 2006). The diverse range of economic backgrounds, beliefs, values and motivations pose increasing challenges to managers tasked with finding solutions to wildlife conflicts. This discord is likely to become more difficult in the future if people become more and more detached from nature and ignorant about wildlife and conservation. Management solutions will be dependent on finding a precarious balance between the rights of individuals, monetary losses and the preservation of the environment for future generations.

Impacts on Wildlife

Though loss of habitat is the primary cause of species decline (Ehrlich and Wilson 1991, Soulé 1991, Pimm and Raven 2000), there is a growing consensus that the proximate mechanisms for the accelerating loss of terrestrial biodiversity and species extinctions are often indirect and asymmetrical (DeCesare et al. 2010). Conservationists are beginning to recognize the importance of indirect and complex (nonlinear) interactions in driving population dynamics (Polis and Strong 1996, Sinclair and Byrom 2006). Indirect effects of development include altered animal and plant community composition and biotic interactions, fragmentation of natural land cover, avoidance of areas near development or human activity, as well as the establishment of source-sink dynamics. All of these mediators have been linked to modified species behavior, interrupted dispersal and movement patterns, and habitat alterations which can impact population dynamics, distributions and decrease biodiversity (Odell and Knight 2001, McKinney 2002, Miller et al. 2003, Glennon and Kretser 2005, Hansen et al. 2005, McKinney 2008).

In general, increased housing densities result in a decrease in native species sensitive to human disturbance and an increase in generalist human adapted species (Schneider and Wasel 2000, Maestas et al. 2003, Fraterrigo and Wiens 2005, Hansen et al. 2005, Lenth et al. 2006, Gude et al. 2007, Blair and Johnson 2008). This results in biotic homogenization as urban-adaptable species such as coyotes (*Canis latrans*), red foxes (*Vulpes vulpes*), raccoons (*Procyon lotor*), skunks (*Mephitis mephitis*), European starlings (*Sturnus vulgaris*), house sparrows (*Passer domesticus*) and early successional plant species become increasingly abundant (Hayden 1975, McKinney 2002, Fraterrigo and Wiens 2005, McKinney 2006, Kretser et al. 2008). Development can also lead to a loss of native species richness through competition with invasive exotic species (Radeloff et al. 2005). Humans physically transport and introduce invasive species into new areas as well as provide disturbed habitat that can be utilized by competitive non-native species (D'Antonio and Meyerson 2002, McKinney 2006). Predators and large mammals are often the first species to decrease near human development due to active persecution, low reproductive rates and extensive resource needs (Ray et al. 2005). The loss of both vertebrate and invertebrate predators can lead to overabundant prey species in some areas or increase the competitive ability of non-native species (Shochat et al. 2004). Extreme consequences of altered species abundance and distribution can impact ecological community dynamics through trophic cascades that are mediated by human activity (Crooks and Soule 1999, Hebblewhite et al. 2005, Berger and Conner 2008, Berger et al. 2008).

In certain cases, predators can benefit from human modified landscapes when resource availability is altered. Subsidized predators occur when humans directly or indirectly create resource subsidies that allow predators to maintain population levels above what would occur without additional resources (Gompper and Vanak 2008). Common Ravens (*Corvus corax*) receiving subsidies from garbage dumps near human developments have been shown to hunt threatened desert tortoises (*Gopherus agassizii*) in the Mojave Desert (Boarman 2003, Kristan and Boarman 2003, Boarman et al. 2006). Similarly, generalist coccinellid beetles subsidized in croplands displayed increased predation pressure on native aphid herbivores in natural habitat remnants (Rand and Louda 2006) and red fox subsidized by human farmlands had behavioral effects on gerbil (*Gerbillus spp.*) foraging levels in the desert of Jordan (Shapira et al. 2008). Thus, subsidies can have a strong impact on population interactions and the structure of the ecological community (Polis et al. 1997).

Fragmentation of intact landscapes has diverse effects on different species. In general, development often reduces habitat from its original extent to a series of disconnected small patches (see review by Saunders et al. 1991). This results in decreased connectivity between patches, overall loss of habitat and an increase in edge habitat, all of which can decrease the ability of an area to support individuals and populations (Glennon and Kretser 2005). For example, the human population in an area of exurban growth near Seattle, WA increased by 193% between 1974 and 1998. This resulted in increased forest fragmentation and reduced interior forests > 200 m from an edge by 60% (Hansen et al. 2005, Robinson et al. 2005). Other studies have found that the loss of mature forests can decrease native forest bird abundance (Hansen et al. 2005). In Ontario, an increase in the number of houses near forest patches (irrespective of the size of the patch) decreased the diversity and abundance of Neotropical migrant songbirds, suggesting that any external residential development had a large impact on forest communities (Friesen et al. 1995). An increase in edge habitats as a result of fragmentation can alter disturbance regimes and biotic interactions and lead to invasion of non-native species as described above (Dale et al. 2005).

Fragmentation is a result of the conspicuous alterations to the environment through exurban development. These changes include the construction of linear features such as roads, fences, power lines as well as buildings. The associated human disturbance is often difficult to quantify but can include increased recreation in surrounding areas, traffic levels, noise, human presence, security lights and domestic pets (Knight et al. 1995). Avoidance of human development and disturbance can lead to an extensive loss of habitat effectiveness. Avoidance can be defined as a reduction in use of areas near human activity compared to areas farther from development. Various species have been shown to alter behavior and habitat use near human activity (Theobald et al. 1997, Odell and Knight 2001, Vistnes and Nellemann 2008, Polfus et al. *in review*). Patterns of avoidance vary with respect to species, sex, age, season, density dependence, size of the area affected and development type. Furthermore, roads can act as barriers to movement, encourage new residential development, increase soil erosion and sedimentation and promote foreign chemical transport, all of which cause further habitat degradation to the local system (Forman and Alexander 1998, Trombulak and Frissell 2000, Hawbaker et al. 2006).

Some species may be sensitive to the associated increase in human activity around development. Roads and residential developments facilitate additional human activities such as hunting, resource extraction and recreation. Areas surrounding residential developments also experience increased authorized and unauthorized use (Henderson and O’Herren 1992). Domestic pets can be efficient and effective predators and can impact the distribution and abundance of native species. Studies have shown that domestic dogs impact the behavior of white-tailed deer and mule deer but demographic impacts were not tested (Hayden 1975, Sime and Schmidt 1999, Miller et al. 2001). However, other studies have shown direct mortality of fawns due to dog predation in New Brunswick (Ballard et al. 1999). There is substantial evidence indicating that domestic cats can have severe impacts on songbird, small mammal and reptile populations and are an increasing threat to biodiversity (Coleman and Temple 1996, Crooks and Soule 1999).

There is growing concern that areas near roads and human developments may be attractive population sinks for a number of species. In these situations, individuals select risky habitats (most likely due to high quality forage, for example; near roadsides) which decrease survival through increased mortality rates (Nielsen et al. 2006). These habitats are often called attractive sinks (Pulliam 1988) or ecological traps (Gates and Gysel 1978) where individuals experience high mortality, but populations are maintained by immigration from source areas with positive reproduction and recruitment. Attractive sinks are common in habitats that have been altered by humans because species are unable to recognize or adapt to mortality risks that were not present in their evolutionary history (Delibes et al. 2001, Donovan and Thompson 2001, Schlaepfer et al. 2002). The interactive effects between public and private lands in the West can produce complex population dynamics. Hansen and Rotella (2002) found that undeveloped productive low-elevation private lands act as a source for native bird species in the Greater Yellowstone Ecosystem. However, when residential development occurred in these areas, nest success declined due to brood parasitism by cowbirds. These dynamics suggest that ranchlands and other private lands should be an important focus of conservation efforts (Maestas et al. 2003).

Understanding the interactions of multiple development types across large temporal and spatial scales is important for predicting how future developments may impact populations. Different types of human disturbance, such as roads or houses, are likely to have varying degrees of influence on the strength of avoidance and have the potential to interact in a cumulative manner with habitat quality and local population dynamics (Polfus 2010). In this way, a single road may be individually inconsequential, but the combined impact of multiple roads and development complexes can be significant over time (Spalding 1994, Jeffrey and Duinker 2000, Scott 2007). Current management policy, which often attempts to mitigate impacts by restricting development through timing or seasonal restrictions, is unlikely to mitigate environmental degradation from the increasing exurbanization. Wildlife persistence is unmistakably dependent on available habitat – habitat which is quickly being compromised by extensive development across the United States. The scale and measured process of piecemeal development in exurbia further confounds the ability of land planners to address cumulative effects. Single development permits, authorized over the span of years can make it difficult for review boards and planners to decline building permits when an area already contains multiple houses (Travis 2007). Thus, the cumulative impact of multiple low-density residential developments can produce significant ecological effects over time.

Impacts on Society

The spread of residential development into rural and undeveloped areas not only threatens wildlife habitats, but also has many negative social impacts that are often overlooked. For example, rural sprawl puts increasing pressure on public facilities and services such as hospitals, libraries, schools, fire stations and law enforcement. Often these services are not supported by revenue from exurban tax dollars and deplete local government budgets (Gude et al. 2006). Rural sprawl also decreases the efficiency of power lines and roads, increases the costs of transportation, separates low income families from jobs and disrupts community cohesion (Ewing et al. 2005, McElfish 2007). These hidden costs have been linked to increased traffic fatalities (Ewing et al. 2003a), increased pollution, obesity (Ewing et al. 2003b) and disturbance to aquatic ecosystems and water quality (Wear et al. 1998, Nassauer et al. 2004).

Land use change in areas where undeveloped land meets development poses serious threats to human quality of life and safety as well as the environment. This abutment zone has been termed the wildland-urban interface (WUI), and some estimates suggest that it occupies close to 9% of the U.S. (Radeloff et al. 2005). A host of environmental problems are associated with the WUI including alteration of ecological process, energy flows and natural disturbance regimes such as the frequency of pest outbreaks, fires, floods and blowdown events (Dale et al. 2005). The increase in exurban development has made managing wildfires challenging, costly and dangerous (Radeloff et al. 2005, Travis 2007, Gude et al. 2008). In Western states, 50% of new homes are built in areas classified as severe fire zones, increasing the exposure of people and structures to wildfire (Theobald and Romme 2007). Exurban development can also influence the stability of sensitive riparian areas and increase the risks of floods that can impact both ecological systems and in some cases human communities (Johnson 2001, Hansen et al. 2005).

Where residential units are adjacent to undeveloped areas, there is generally an increase in human-wildlife interactions and conflicts (Wolch et al. 1995, Woodroffe et al. 2005). Conflicts can result from direct experiences such as deer-vehicle collisions, crop-depredations, scorpion stings or direct attacks on humans by predators (Lacey et al. 1993, Baker and Timm 1998, McIntyre 1999, Riley and Decker 2000). Development patterns can have a significant impact on the rate and severity of human-wildlife interactions. McIntyre (1999) found that the number of reported scorpion stings around Phoenix, Arizona, increased in areas of low-density residential housing (<5 units per acre) and that the proximity to undeveloped land was also a good predictor of the frequency of stings. In northern New York near Adirondack Park, Kretser et al. (2008) modeled the spatial distribution of species-specific human-wildlife interactions across a range of housing densities. Interaction reports were clustered in the center of the urban-rural gradient with more conflicts reported in low-density suburban and exurban areas compared to urban areas and wildlands.

Threats to property and human safety can impact people's perceptions of wildlife and set back local conservation efforts (Conover 1998). Societal characteristics influence the beliefs, attitudes, and behaviors humans have towards wildlife. Studies have found that tolerance towards wildlife tends to decrease as the number of interactions increases (Lacey et al. 1993, Kretser et al. 2009, Thornton and Quinn 2009). In New York state, negative outlooks towards wildlife were associated with older, lower income residents who had less experience with wildlife (Kretser et al. 2009). However, risk perception is also a function of historic cultural attitudes and media coverage of serious conflicts (Wolch et al. 1995, Riley and Decker 2000, Hudenko et al. 2008). Supporting projects that increase positive interactions between people and wildlife, such as bird watching, is an important consideration since people with positive interactions with wildlife are more willing to support local wildlife management programs (Kretser et al. 2009). The management of human-wildlife conflict is undoubtedly dependent on managing human behavior. Wildlife managers must be able to respond to issues with appropriate methods to decrease risks to human welfare while at the same time promoting wildlife and habitat conservation.

Unfortunately, the amenities that draw people to the West, such as scenic beauty, wildlife and open spaces are being destroyed by houses owned by the very people who value these qualities in the first place. The propensity for well educated, environmentally oriented people to live in natural areas is a troubling pattern for conservation (Peterson et al. 2008). There is a need for people concerned about the environment to change ingrained behaviors, such as choice of household location, that are threatening wildlife habitat (Peterson et al. 2008). Altering established societal systems will be exceedingly difficult, but conservation biologists will be forced to tackle these issues in the face of growing residential development across the Western U.S.

> "The biggest problem is the loss of winter range (for mule deer and elk), and I've now become part of it because my wife won't live in town."
>
> – Retired Idaho Fish and Game biologist quoted in Peterson et al. (2008)

Ungulates

Ungulate Winter Range

Habitat represents the resources and environmental conditions in an area that determine the survival and reproduction of a given organism (Hall et al. 1997, Sinclair et al. 2006). Ungulates must select resources to sustain a positive energy balance, minimize energetic costs and reduce predation risk across broad temporal and spatial scales (Altendorf et al. 2001, Lind and Cresswell 2005). In the northern hemisphere, digestible nutrients and protein decline during the winter and snow accumulation increases energy loss during movement (Ungulate Winter Range Technical Advisory Team 2005). Thus, ungulate winter range must provide security and thermal cover and allow ungulates to maximize forage intake and minimize energy loss through movement (Figure 4., Armleder et al. 1994). However, many ungulates still experience a negative energy balance during winter as a result of increased energetic costs of gestation for females (Pekins et al. 1998), deep snow events (Parker et al. 1984, Fancy and White 1987) and loss of fat and protein due to low quality winter nutrition (Torbit et al. 1985, Festa-Bianchet 1989, Parker et al. 2009).

Winter range is highly variable between regions and species due to the exogenous effects of climate, topography, landcover, predation and the influence of human development (Figure 4., Sweeney and Sweeney 1984, Safford 2003). Because of these differences, specific requirements of winter range for mule deer, white tailed deer, elk, American pronghorn and bighorn sheep will be described in more detail in the following sections. However, it is possible to make a few general observations about ungulate winter range. Snow is likely the single most important aspect of winter range in climates that experience extreme weather events (Poole and Mowat 2005). Snow depth, density and hardness determine the amount of forage that can be reached (Harestad 1985), ability of ungulates to avoid predators and the timing of fine scale daily habitat selection movements and migration (Parker et al. 1984). Ungulate response to various snow depths (or more correctly sinking depths) is well documented in the literature for a number of species (Pruitt 1959, Kelsall 1969, LaPerriere and Lent 1977, Parker et al. 1984, Sweeney and Sweeney 1984, Pauley et al. 1993). Because of the implications snow depth has on ungulate energetics, forested habitats where canopy cover reduces snow on the ground can be an essential component of winter range. Old growth closed-canopy forests are used by ungulates as movement corridors and can also provide arboreal lichen as forage (Armleder et al. 1994), moderate temperatures and hiding and escape cover (Toweill and Thomas 2002). In mountainous regions during periods of heavy snow, ungulates use low elevations and west and south facing slopes where snow is more likely to melt (Kelsall 1969, Henderson and O'Herren 1992, Pauley et al. 1993). Because digestible forage is generally more abundant in open areas ungulates must make trade-offs between the benefits and costs of forest cover, snow depth and forage availability (Pauley et al. 1993, Serrouya and D'Eon 2008).

Determining the amount of winter range required to sustain an ungulate population is difficult because nutritional value of forage, snow accumulation, density and quality, climate, predation and proximity to human development all influence the quality of winter range. Ungulates generally require smaller areas when quality is high and larger areas when quality is low (Anderson 2005), though there are exceptions to this rule (Hoskinson and Tester 1980). Most ungulates exhibit high fidelity to winter range, but habitat preference can change in response to development, winter severity, or predation pressure (Nelson 1998, Hebblewhite et al. 2005, Sawyer et al. 2006, Hurst and Porter 2008). Migration pathways to and from winter range also contribute to habitat quality (Sawyer et al. 2009b).

Because most private land occurs in valley bottoms and mountain foothills, ranches are often an important component of ungulate winter range. In fact, it is likely that over 50% of the wild ungulates in Montana spend a large portion of time on private agricultural lands (Irby et al. 1997). As private lands are converted to residential development it is probable that high quality ungulate winter range will be lost. Furthermore, though little research has focused on the variation in quality of winter range habitat, it can be assumed that residential development in an area of critical habitat, such as essential escape terrain or thermal cover, has the potential to reduce the overall carrying capacity even if the development footprint is small (Krausman et al. 2011). Some areas of winter range may be important only during some winter conditions, such as icing events, and development on these areas could have large impacts during specific years.

Recent work has also shown summer habitat to be critical because of the importance of summer nutrition to ungulate population dynamics (Cook et al. 2004; Parker 2003). Spring green-up has a large effect on fetal growth and reproduction success (Henderson and O'Herren 1992). Thus, the proximity of summer ranges to wintering areas and the quality of important migration corridors also have important implications for ungulate population viability. Mule deer, white-tailed deer, elk, pronghorn and bighorn sheep commonly migrate between 50 and 100 km in spring and fall (Hoekman et al. 2006, Sawyer et al. 2009b, Williams et al. *In prep*). Unfortunately, these migration routes are increasingly threatened by energy development, tourism, exurban development and highway mortality especially in bottlenecks where options for avoiding development pressure are limited (Berger 2004, Gude et al. 2007).

Conserving undeveloped areas of important seasonal ungulate habitat is a key conservation priority for Montana Fish, Wildlife and Parks. As more and more winter range is converted to residential areas, ungulates are increasingly forced into developed areas during the winter. These animals can become habituated to high levels of human activity resulting in conflicts with humans. Problem animals in urban areas stress the financial capacity and oversight of managers. These animals are not only a threat to human safety through increased vehicle collisions but also cause property damage, spread diseases, alter plant community composition and compromise the human perception of wildlife as natural and free-roaming. Further, by decreasing hunting opportunities, habituated wildlife can reduce revenue from the sale of hunting tags, diminish the flexibility of managers to control ungulate populations and weaken public enjoyment of wildlife. Thus, Montana Fish, Wildlife and Parks defines functional ungulate winter ranges as large unfragmented landscapes of suitable habitat where ungulates occur in a natural wild state during the winter. The characteristics of functional winter range include (Vore 2010):

1. Wildlife can use the habitat undisturbed
2. Animals can move easily to and from summer range
3. There are no conflicts with people and domesticated pets
4. Traditional human use and enjoyment of the animals is maintained
5. All options for effective wildlife management, including hunting with rifles, can be employed if desired

Differentiating between ‘functional’ and ‘non-functional’ winter range can help direct conservation priorities.

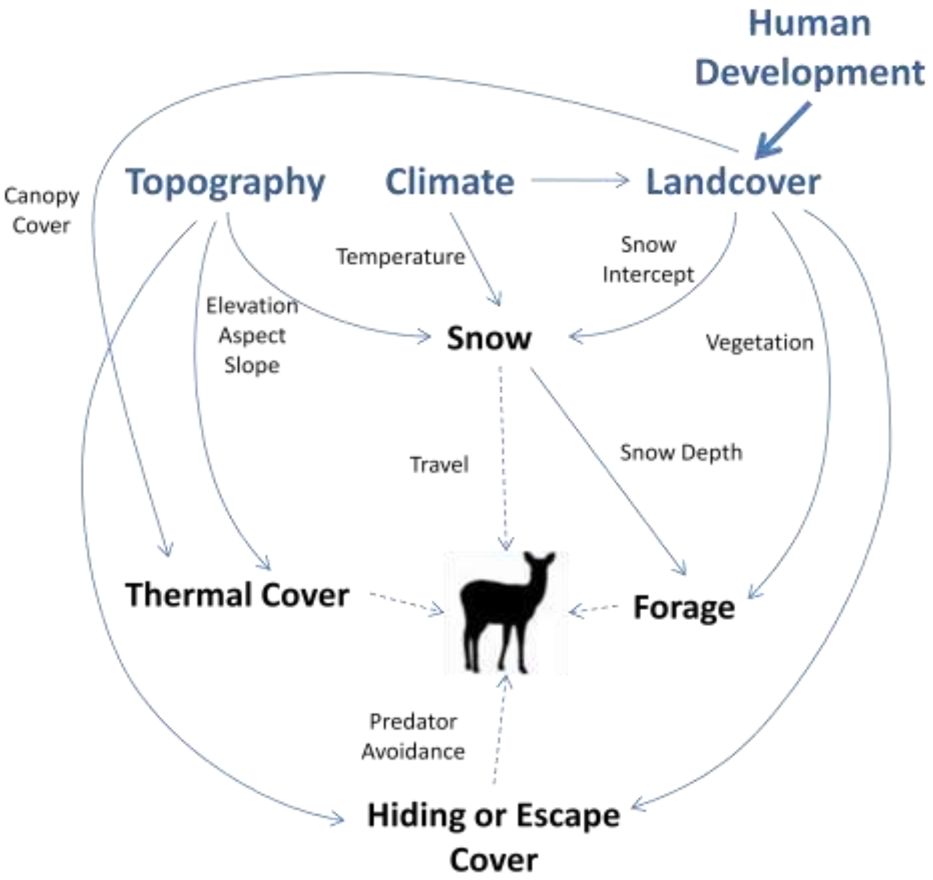


Figure 4. Factors affecting the energy balance of ungulates during the winter. Dashed lines represent factors that influence the condition of ungulates and solid arrows represent factors that influence attributes of winter range habitat. Adapted from Safford (2003).

Impacts of Human Development on Ungulates

As discussed earlier, recent evidence suggests that the effects of human activity and development on wildlife can have non-linear asymmetrical impacts on individuals and populations. Making comparisons across studies of species responses to development can be difficult due to differences in methodology, techniques, regulatory measures, and the scale of the impact examined (Johnson and St-Laurent 2011). In general, the lack of unifying theory has made it challenging to identify universal principles of wildlife-development interactions across studies, taxonomy and development types. Johnson and St-Laurent (2011) have recently proposed a typology for wildlife impact research that sets up a framework for classifying and predicting the impacts of human-wildlife interactions and can serve as a starting point for comparing divergent studies. This framework highlights three broad categories of effects (the spatiotemporal dimensions of the effect, the magnitude of the effect and the regulation and mitigation of the effect) that interact hierarchically to alter the scale of the biological impact on the species. In this way, the range of impacts and effects can be unified by examining the spatial and temporal scale of the response.

Studies that examine avoidance of human development often vary greatly in methodology, with techniques ranging from aerial and ground surveys, pellet counts, movement rates and analyses of telemetry data (Picton 1980, Vistnes and Nellemann 2001, Weir et al. 2007, Cleveland 2010). Notably, recent research suggests that the scale of assessment has a strong influence on the probability of detecting impacts (Hebblewhite 2008, Vistnes and Nellemann 2008) . For example, research on caribou and reindeer (*Rangifer spp*) shifted from local to regional scales in the 1990s. Data that included wider temporal and spatial scales revealed *Rangifer* avoid industrial development, where earlier local behavioral studies had found negligible or indecisive effects (Vistnes and Nellemann 2008). Similar patterns have been detected in other species (Johnson et al. 2005, Nielsen et al. 2008).

Disparate techniques have lead to political and scientific controversy regarding the effect of human activity on ungulates, especially when stakeholders have a vested interest in the interpretation of avoidance distances (Wolfe et al. 2000). Many regulatory processes identify a zone of influence (ZOI) around developments where species experience impacts. The width of a ZOI buffer (the distance of avoidance) is often based on expert opinion or published literature (Anderson et al. 2002, Gallagher et al. 2004, Johnson et al. 2005, Florkiewicz et al. 2006).

However, the ZOI is dependent on biological scale being investigated, the season, the type of development, type of response measured and other biologic factors which can make measuring significance difficult (Gunn et al. 2011). In northern British Columbia, biologically relevant ZOI were developed based on locations from GPS collared woodland caribou (*Rangifer tarandus caribou*) to determine the avoidance of multiple types of human developments (Polfus et al. *in review*). Avoidance of each development type (cabins, town, mines, high use roads and low use roads) varied between seasons and scales, highlighting the importance of cumulative effect studies, which require wider temporal and spatial scales in order to describe population level effects (Krausman 2011).

Many studies and reviews have focused on comparing biophysical-behavioral forces such as home range size, movement rates, annual survival and fertility rates between studies of ungulates along the urban-rural gradient (Kilpatrick and Spohr 2000b, Krausman et al. 2011). While these comparisons may shed light on some general responses to human disturbance, specific environmental conditions in each study area as well as significant differences in methods makes this type of comparison difficult. For example, many studies have shown that estimates of home range size vary due to the estimation techniques especially with the increased reliance on GPS collars (Getz and Wilmers 2004, Getz et al. 2007, Johnson and Gillingham 2008, Kie et al. 2010). Clearly, understanding home ranges, and more importantly, the underlying behavioral mechanisms that explain how and why animals use space, go far beyond the absolute size of the estimated area. Further, the validity of the home range size depends on the scale of the biological question being asked.

The magnitude of the effect also influences the consequences of development on ungulates. Direct habitat loss is easily measured and simply calculates the amount of area converted to human structures. These structures will decrease available habitat in some cases and may also act as barriers to movement and alter metapopulation dynamics (Dyer et al. 2002). The total magnitude of the effect depends both on the total area converted as well as the temporal scale of the exposure to development activity (Johnson and St-Laurent 2011). Single isolated activities may have a trivial impact on ungulate behavior or demography (Oehler et al. 2005), while effects that are large-scale and accumulate over time generally have a larger impact on populations (Nellemann and Cameron 1998). Again, different research designs and metrics used to assess the effect will alter the detection of impacts. Finally, Johnson and St-Laurent (2011) argue that the eventual outcome of development on wildlife is also a result of the types and effectiveness of regulatory frameworks. The importance of policies that effectively provide restrictions and guidelines on the location, size and appropriateness of new developments cannot be over-stated. When the management process becomes self-regulatory the resulting impact on species is more likely to have population or community-level consequences.

Biological Scale of Impact

Individual Behavioral Responses

The framework for identifying the biological scale of the impact developed by Johnson and St-Laurent (2011) provides a hierarchical structure for understanding how various effects of human development influence ungulates. The incremental increase in the severity of the observed biological impact likely does not follow a completely linear relationship, but does reflect a general continuum from individual behavioral responses and physiological changes to population and community-level impacts that have broad implications for population viability (see Table 3., Johnson and St-Laurent 2011). Short-term behavioral changes such as movement away from disturbance, flight response, increased vigilance, altered foraging rates and changes in maternal activities are often the first response ungulates exhibit when their environment is modified (see reviews by Frid and Dill 2002, Stankowich 2008). These changes can be monitored through observational studies, analysis of distributions, indirect measures of habitat use or radio-telemetry. Behavioral changes are a result of multiple non-additive factors (life history, disturbance level, group size, season, etc.) that influence ungulate decisions to flee or stay in an area (Stankowich 2008). In general ungulates assign different levels of risk to different stimuli. Response can vary from minor increased vigilance to panicked flight depending on numerous variables such as prior disturbance and habituation, season, quality of cover, distance from stressor, visibility and other environmental factors (Webster 1997). Often loud noises, aircraft or vehicular stimuli have less of an impact on ungulate responses than pedestrian approach (MacArthur et al. 1982, Andersen et al. 1996, Harrington 2003, Stankowich 2008).

Both direct and indirect impacts can result from increased human development, activity and infrastructure. Anthropogenic mediated mortality of ungulates can occur through hunting, poaching, collisions with vehicles, domestic animal predation, and injuries from building structures and toxins (Burton and Doblar 2004, Krausman et al. 2011). Avoidance and displacement from optimal habitat can be considered a form of indirect habitat loss. For example, studies have documented that caribou and reindeer avoid areas near roads, seismic lines, oil well sites, human settlements, tourist resorts and cabins, power lines, hydroelectric developments, mine sites, logging clearcuts, and snowmobile activity (Dyer et al. 2001, Nellemann et al. 2003, Schaefer and Mahoney 2007, Seip et al. 2007). Displacement from optimal foraging grounds could lead to less suitable habitats and cause crowding and overgrazing (Nellemann et al. 2003). Avoidance may influence individuals' ability to circumvent harsh snow conditions and local habitat variables. Displacement also has the potential to alter predation risk by making ungulate locations more predictable and thus more vulnerable to hunting by animal predators and humans (Stuart-Smith et al. 1997, James and Stuart-Smith 2000, Dyer et al. 2001). However, while disturbance may produce similar effects, the impacts are almost always species-specific. This highlights the need for long term studies that examine the impacts of different development types on a range of species.

When disturbance frequency is regular or constant, ungulates have been shown to become habituated to human activity, though levels of habituation vary among individuals and populations (Stankowich 2008). Moose (*Alces alces*), white-tailed deer and elk populations have all shown high adaptation to human habitation (Thompson and Henderson 1998, Kilpatrick and Spohr 2000a, Kloppers et al. 2005, Walter et al. 2010). For example, in Anchorage, Alaska, moose numbers in the city can increase to over 1,000 individuals in the winter and moose are becoming an escalating hazard to drivers (Rozell 1999). Hunting has been shown to decrease habituation towards humans, but in some cases seasonal hunting may not provide enough constant negative stimuli to override other forms of recreation (Colman et al. 2001).

Individual Physiological Responses

Responses to human activity may also include altered physiological, energetic or nutritional states (Johnson and St-Laurent 2011). In ungulates these responses include increased heart rate, respiration and stress hormone concentration (Macarthur et al. 1979, Creel et al. 2009). In some cases, heart rate may increase during disturbance but quickly decrease to pre-disturbance levels with little impact on behavior or habitat use (Krausman et al. 1998). However, prolonged disturbance events may cause increased vigilance, reduced feeding time and lower nutrient intake which have been shown to reduce reproductive rates (Nellemann and Cameron

1996, Cameron et al. 2005). Energetically, flight responses may also increase movement costs and have the potential to reduce body condition and mass and possibly survival (Johnson et al. 2002). Because of the high energy requirements for gestating and lactating females, body condition has direct consequences on the timing of parturition, birth mass and early survival of offspring (Parker et al. 2009). Energetic models for caribou suggest that the energy costs associated with multiple noise disturbance events over the winter could result in a loss of 15% body mass (Bradshaw et al. 1998). Females with calves are especially sensitive to disturbance and may select low quality forage to avoid predation risk (Festa-Bianchet 1988, Poole et al. 2007). Non-invasive techniques have the potential to increase our understanding of physiological status through analysis of parasite loads to examine fitness (Hughes et al. 2009), monitoring of stable isotopes to measure nutritional quality (Parker et al. 2005) or fecal glucocorticoid hormones to measure physiological stress responses (Creel et al. 2002). Unfortunately, most management and regulatory efforts are reactionary and focus on attempting to reverse declines that are already severe (Ludwig et al. 1993). Therefore, understanding key nutritional, physiological and behavioral changes in individuals may provide managers with the opportunity to mitigate the impacts of human disturbance before large-scale population declines occur (Creel et al. 2002).

Population Responses

Behavioral and physiological responses by ungulates to disturbance are by far the most studied impact due to the ease of monitoring and detecting changes. However, disturbance is only important if it decreases vital rates such as reproduction or survival and leads to a population decline (Gill et al. 2001). This information is crucial for managers who must recognize and predict how future developments will influence population dynamics. Few studies have been able to link short or long-term behavioral or physiological responses to changes in abundance, distribution or demography (Hebblewhite 2011, Johnson and St-Laurent 2011). However, when disturbance is severe, physiological or behavioral changes will alter vital rates and be detected at higher biological scales. These inferences are needed to evaluate the effectiveness of management strategies, understand and predict the effects of development and monitor regulatory requirements (Stankowich 2008, Johnson and St-Laurent 2011). Unfortunately, few firm conclusions exist about the population level impacts of human development on ungulates (Hebblewhite 2011). Because ungulates are generally long-lived, the effects of development on sensitive vital rates, such as adult female survival, are extremely difficult to measure in 2-3 year studies. Compensatory reproduction and resilience in adult age-cohorts create time lags between the effects of development and the eventual impact on the species. Without detailed demographic data, the mechanisms driving changes in abundance and distribution are impossible to determine with confidence (Hebblewhite 2011).

However, some studies have documented large scale range abandonment in response to development. The construction of a large hydroelectric reservoir (and associated power lines and roads) in southwestern Norway, resulted in a 92% decline in reindeer density within 4 km of infrastructure over a 10 year period. Areas more that 4 km from roads and power lines experienced a 217% increase in reindeer use. Cow:calf ratios declined as habitat was lost, most likely due to loss of high quality summer range (Nellemann et al. 2003). In south-eastern British Columbia, Seip et al. (2007) used resource selection functions to demonstrate caribou displacement from preferred winter habitat by snowmobiles. Caribou were not found in areas of high snowmobile use over several years in mountain blocks. Habitat modeling indicated that significantly lower numbers of caribou were using snowmobile habitat than expected based on habitat quality.

Finally, human development can result in large scale range contractions and local extirpations. Laliberte and Ripple (2004) examined historic range contractions for North American ungulates and found that many were less likely to persist in areas of high human influence. Specifically, range contractions resulted in 74% loss of historic range for elk, 64% loss for pronghorn, 25% loss for bighorn sheep, 24% loss for caribou, 11% loss for moose and 8% loss for mule deer. Alternatively, white-tailed deer range expanded by 6%. These contractions are important to keep in mind when examining the response to development of remaining populations that have persisted. It is likely that many areas now occupied by residential developments, towns and cities were once critical ranges for elk, pronghorn, bighorn sheep and mule deer.

Ecological Community Responses

Proximity to human development may also alter interspecific relationships such as predation and competition and thus influence the ecological community composition and distribution (Johnson and St-Laurent 2011). For example, evidence suggests that high white-tailed deer densities have extirpated black bears (*Ursus americanus*) on Anticosti Island in Québec (Cote 2005) and black-tailed deer populations (*Odocoileus hemionus*) alteration of native vegetation negatively impacts songbird populations on the Gulf and San Juan Island archipelagos of western Canada and the United States (Martin et al. 2011). Predators have a major impact on prey species and in some cases contribute to species declines and extinctions (Sinclair et al. 1998). These impacts can result from direct effects of predation or be mediated through indirect effects that may cascade through a community (Ripple et al. 2001, Hebblewhite et al. 2005, Berger et al. 2008). Human-altered landscapes can disrupt natural predator-prey relationships since apex predators are more susceptible to extirpation due to conflict with humans (Ray et al. 2005). Because of this, human developments can be attractive to ungulates due to the inherent avoidance of human infrastructure by predators such as wolves (*Canis lupus*) and grizzly bears (*Ursus arctos*). In Anchorage, moose exploit the city for protection from nearby wolf packs in the winter (Garrett and Conway 1999). In the Greater Yellowstone Ecosystem, Berger (2007) found that female moose chose sites closer to roads to give birth, likely as a shield against predation by grizzly bears. In southeastern British Columbia, Kunkel and Pletscher (2000) compared sites where moose were killed by wolves to random locations from radio collared moose. Their results suggest that moose were less likely to be killed by wolves in areas of high road density. Though wolves use roads to enhance travel and searching speeds, the risk of encountering humans on roads may have offset any hunting efficiency benefits.

Conversely, some predators may be drawn into exurban areas by abundant prey species and anthropogenic foods resulting in increasing conflict with humans (Baker and Timm 1998). For example, mountain lion (*Puma concolor*) -human interactions are increasing in the West (Riley and Decker 2000), and coyote populations have increased in residential areas (Grinder and Krausman 2001). As a consequence, a favorable public perception of wildlife may decline due to perceived risks to property and personal safety (Riley and Decker 2000, Hudenko et al. 2008). However, human dimensions research has revealed that the duration and quality of experience with carnivores can interact to influence risk perceptions. For example, resident attitudes towards mountain lions were positive near Calgary, Alberta, and the residents with the most experience with mountain lions were more accepting of management actions and hunting (Thornton and

Quinn 2009). Education of the public about the actual risks associated with wildlife can improve public relations and increase management options.

In circumstances where predator populations are subsidized by an alternative prey species, natural predator-prey dynamics can become decoupled and increased predation can drive the native prey to extinction (DeCesare et al. 2010). For example, in Alberta, human development has altered predator-prey relationships by providing young seral forests that are preferred by moose and white-tailed deer and subsequently, predators such as wolves. High wolf densities consequently increase the vulnerability of woodland caribou to predation (James et al. 2004, Latham et al. 2011). Linear developments such as roads and seismic lines may also increase the mobility of wolves. In northeastern Alberta, James and Stuart-Smith (2000) found that caribou have higher risk of predation from wolves near linear corridors. Seismic lines, which have low human use, may be preferentially used by wolves, increasing their travel efficiency and the ease of caribou detection. Even a small increase in predation through altered spatial relationships between ungulates, predators, and alternate prey could lead to population level effects in herds with low growth rates.

Table 3. Ungulate response to development along the continuum of the biological scale of impacts as described by Johnson and St-Laurent (2011).

Biological Scale of impact	General Ungulate Response	Monitoring Methods	Key Research
Individual Behavioral Responses	Movement away from disturbance, flight response, ↑ vigilance, altered foraging rates, changes in maternal activities, avoidance of development and habituation. Loud noise, aircraft & vehicular stimuli < impact than humans on foot.	Observational studies, analysis of distributions, indirect measures of habitat use or radio-telemetry.	Reviews by Frid & Dill 2002 and Stankowich 2008
Individual Physiological Responses	↑heart rate, respiration and stress hormone concentration. Prolonged disturbance events may cause ↑ vigilance, reduced feeding time and ↓ nutrient intake → ↓ reproductive rates. Body condition influences the timing of parturition, birth mass and early survival of offspring.	Analysis of parasite loads, monitoring of stable isotopes and fecal glucocorticoid hormones.	Review by Parker et al. 2009, research by Creel et al. 2002, 2009 and Millspaugh et al. 2003
Population Responses	Prolonged and severe physiological or behavioral changes can alter vital rates and be detected at higher biological scales. Few firm conclusions exist about the population-level impacts of human development on ungulates, but large scale range abandonment has been recorded.	Long-term cumulative effects studies.	Reviews by Hebblewhite 2008, 2011 and Laliberte & Ripple 2004, research by Nellemann et al. 2003 and Seip et al. 2007
Ecological Community Responses	Altered interspecific relationships → community composition and distribution. Indirect effects may cascade through a community. Ungulates may use development as a shield against predators or alternately predators may be drawn to development by abundant prey. Subsidized predators ↓ prey populations.	Large-temporal and spatial scale, multi-level, cumulative effect studies.	Research by Ripple et al. 2001, Hebblewhite et al. 2005, Berger et al. 2008, and Latham et al. 2011

White-tailed Deer

Key characteristics of winter range

White-tailed deer are ubiquitous throughout North and Central America and display a wide range of regional variation in behavior, physiology and demographics (Geist 1998). Defining specific habitat requirements for white-tailed deer is difficult because they are opportunistic generalists. In fact, the diversity of food choices by white-tailed deer makes any attempt to characterize resource selection problematic. As Geist (1998) writes, "to classify deer as browsers obscures more than it enlightens." However, consistent with all northern ungulates, white-tailed deer must balance metabolic costs of movement and predator avoidance with forage availability. In areas without severe seasonal weather conditions, white-tailed deer will occupy the same range year round (Alexander 1968, Sparrowe and Springer 1970, Larson et al. 1978). However, snow depth has a significant influence on white-tailed deer body condition and behavior in the northern part of their range (Telfer 1978, Garroway and Broders 2007). In eastern North America, white-tailed deer often congregate in low-elevation winter yards in response to increasing snow depths (Tierson et al. 1985, Lesage et al. 2000, Hurst and Porter 2008). Extensive use of these areas can severely deplete available browse and can occasionally lead to starvation (Potvin et al. 1981). While some studies suggest that site fidelity to winter range is likely highly plastic, allowing deer to respond to variable browse quality, winter severity or the influence of human disturbance such as fire, timber harvest or bait sites (Tierson et al. 1985, Lesage et al. 2000, Grund et al. 2002, Kilpatrick and Stober 2002, Hurst and Porter 2008), other research points to high fidelity to winter ranges (Woodward 2000, Porter et al. 2004, Hoekman et al. 2006, Klaver et al. 2008).

In the Rocky Mountain West, white-tailed deer are often migratory, moving 20 – 30 km between distinct seasonal ranges (Hoekman et al. 2006). When snow is minimal, deer use open low-elevation habitats to maximize forage on forbs and woody browse (Smith 1977, Telfer 1978). Deer are known to select agricultural land, shrub land, aspen forests, riparian zones and areas near humans that provide high quality forage in suburban lawns (Safford 2003, Krausman et al. 2011). Studies in Montana, Idaho and British Columbia suggest that white-tailed deer adopt an energy conservation strategy when snow depths exceed 30 – 40 cm (Smith 1977, Pauley et al. 1993, Hoekman et al. 2006). To increase efficiency white-tailed deer become dependent on mature conifer stands with > 80% canopy cover that intercept snow and mitigate movement costs. Tree species important to white-tailed deer winter range vary widely between regions and can include ponderosa pine, Douglas fir, Engelmann spruce, western red cedar and western hemlock (Jenkins and Wright 1988, Pauley et al. 1993, Sabine et al. 2002, Hoekman et al. 2006, Klaver et al. 2008). Southwestern aspects are also selected for increased insulation and snow melt rates. Thus, in the Rocky Mountains ideal winter range is characterized by a mix of open habitats with diverse forage and browse that are in close proximity to mature forest stands.

Response to Development

Observational studies have recorded short-term behavioral responses of white-tailed deer subjected to various human stimuli (Kucera 1976, Hirth and McCullough 1977, Lagory 1987, Caro et al. 1995, Lingle and Wilson 2001). In general, white-tailed deer display a variety of predator-avoidance behaviors and physiological responses to disturbance events such as alerting and orienting to the approaching human, tail-flagging, flight (Lingle and Wilson 2001) and increased heart-rates (Moen et al. 1982). Deer are more likely to respond to approach from humans on foot (average flushing distance 122 m), then to humans on horseback or in a truck in Manitoba (Kucera 1976). These reactions may cause deer to use areas farther from human developments if they perceive human activity as a threat. However, white-tailed deer populations have increased steadily since the early 1900s and have expanded into urban and suburban areas where they have adapted remarkably well to human activity (Swihart et al. 1995).

Research on white-tailed deer biology and ecology is substantial and includes numerous studies specific to population dynamics and behavior in residential areas (Table 4). White-tailed deer rapidly reach high densities in suburban and urban landscapes (see comparison of densities in Krausman et al. 2011:169) in part due to decreased movements and dispersal, decreased mortality from hunting, lack of large mammalian predators and increased availability of ornamental plants, shrubs, fertilized yards and supplemental feeding areas (Swihart et al. 1995). Many studies suggest that survival is generally higher and home ranges are smaller in urban areas compared to rural areas, though diverse monitoring methods and estimation techniques make comparisons between studies difficult (Swihart et al. 1995, Hygnstrom and VerCauteren 2000, Piccolo et al. 2000, Etter et al. 2002, Grund et al. 2002, Porter et al. 2004, Krausman et al. 2011).

In a review of several studies in Illinois and analysis of unpublished data from Connecticut, Swihart et al. (1995) concluded that white-tailed deer commonly habituate to human presence in suburban areas. Snow tracking indicated that deer browsed close to houses in winter where forage species richness was two times greater < 50 m from structures. Deer avoided highly developed areas with > 80 houses/km^2, but survival was approximately equal between rural and urban areas. Kilpatrick and Spohr (2000a,b) monitored VHF collared deer in an affluent residential area of Groton, Connecticut. They found that deer did not avoid development and the number of houses within home ranges was greatest in the winter. In suburban areas the minimum space required during the winter/spring transition was 9 ha of undeveloped land associated with 7 ha of residential development. Bird feeders provided significant food resources for deer and likely drew deer close to houses in March when food availability was limited in forest patches. However, the study area was highly fragmented with very little habitat available far from residential areas, thus the availability of undeveloped areas for deer to select was likely limited. The study did suggest that during the fawning period, the number of houses in the core use area was lowest (Kilpatrick and Spohr 2000b). Sensitivity to human disturbance was also strongest during the spring in Carbondale, Illinois, where white-tailed deer in an exurban landscape tended to avoid human structures during fawning, though the result was not statistically significant (Storm et al. 2007b). Contrary to other studies, Storm et al. (2007) also documented higher survival for deer in exurban areas compared to nearby suburban and rural environments. This could be a result of reduced hunting efficiency and lower vehicle collisions in exurban landscapes (Storm et al. 2007a). Grund et al. (2002) monitored deer in a suburb of Minneapolis, Minnesota. Deer generally avoided areas of high human activity in early summer, but shifted habitat selection to residential areas during a severe winter. The authors suggest that anthropogenic food sources and sheltered areas near buildings may have benefited deer during deep snow events and cold temperatures.

Other research in more rural areas has documented white-tailed deer avoidance of residential areas. In a frequently cited study on the effects of housing on white-tailed deer and mule deer populations, Vogel (1989) documented avoidance of existing development in Gallatin Valley, Montana. White-tailed deer home ranges became smaller and more linear with increasing development. Avoidance of houses increased linearly with housing density. Farmhouses were avoided at distances of < 400 m but beyond 1600 m there was no effect. Deer were less likely to be active when there were >11 houses within 800 m and also shifted to more nocturnal behavior. However, several caveats should be explored. This study was conducted from 1981 – 1983 at the advent of VHF collar technology and thus sample sizes were very low (12 white-tailed deer and 4 mule deer radio collared and monitored for a short time) and the number of locations collected was not reported. Further, because many of the locations were observed from driving routes and in defined study plots there is likely to be sample bias associated with deer locations. Other studies of deer response to exurban growth in the West are needed to confirm the relationships described in this study. Comparatively, in southern Illinois, white-tailed deer in a suburban landscape avoided development and selected for wooded areas (Cornicelli et al. 1996).

Habituation

High densities of white-tailed deer in close proximity to human habitation (sometimes > 70 deer/km^2) can exceed human tolerance levels (Swihart et al. 1995, Siemer et al. 2007, Krausman et al. 2011). The inherent problems associated with habituated white-tailed deer at high densities include the spread disease, increased deer-vehicle collisions, attacks on humans and damage to native and ornamental vegetation and crops (DeNicola et al. 2000, DeVault et al. 2007, Hubbard and Nielsen 2009). Managing habituated white-tailed deer is a human perception issue and generally depends more on conflicting social attitudes about wildlife than deer ecology. Management options include birth control measures, fencing, bans on deer feeding, frightening devices, repellents, trapping, translocation, sharpshooting and managed hunts (DeNicola et al.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2000, Beringer et al. 2002). However, public support for lethal control methods is generally low in suburban or urban areas (Decker and Gavin 1987, Cornicelli et al. 1993, Stout et al. 1997), making the task of minimizing deer-human conflicts difficult.

Deer may use areas near human development and activity as a refuge to reduce predation risk from both native predators and human hunters (Harden et al. 2005, Storm et al. 2007a). Exclusion zones that prevent firearm discharge or hunting in proximity to structures can reduce the proportion of land available for hunting, especially at exurban densities where housing is more spread out and each structure has a disproportionate influence on the landscape (Storm et al. 2007a). In the West, ungulate use of private lands as a refuge has caused increasing controversies and can cost landowners up to $6,353 per year (Lacey et al. 1993). In a survey of agricultural producer attitudes towards wild ungulates in Montana, Irby et al. (1997) found that while white-tailed deer occurred most frequently on private land they received higher tolerance from residents than pronghorn and elk. Several cities in Montana have large suburban deer populations. Management agencies like Montana Fish, Wildlife and Parks must respond to complaints and problems associated with habituated deer. This results in an ineffective and costly use of resources that can anger hunters whose license fees provide the majority of funding for urban deer management where hunting is not possible.

Migration

White-tailed deer have adapted several different migration strategies that are likely dependent on local habitat characteristics (Rhoads et al. 2010). In some situations deer will maintain year-long residency in one area (Hygnstrom and VerCauteren 2000), while in other areas deer may shift home ranges in response to severe weather (Nelson 1998, Sabine et al. 2002, Rhoads et al. 2010). In the northern extent of their range, snow depth often forces deer to migrate 20 – 30 km seasonally between distinct ranges (Hoekman et al. 2006). However, other research suggest that snow might not always be a factor in initiating migrations (Grovenburg et al. 2009).

Studies indicate that migration behavior is learned by fawns following their mothers (Nelson 1998). Evidence of individuals switching strategies between years, however, indicates that migration behavior is likely not obligatory and is flexible enough to respond to winter severity or human development (Nelson 1998, Hurst and Porter 2008). Because white-tailed deer are able to adapt to human activity, it is unlikely that residential development will severely disrupt migrations.

Disease

A range of parasites and diseases are known to infect deer of the genus *Odocoileus.* Chronic wasting disease (CWD), is a fatal infectious prion disease that has recently spread through ungulates in North America (Habib 2010). Because CWD can be spread to uninfected deer through contact with live diseased deer, as well as through ingestion of prions in the environment (shed through feces and saliva) there is an increased potential for transmission where deer are concentrated or habitat is limited (Habib 2010). Residential development that limits available winter range could increase deer congregations and facilitate the spread of disease. In the eastern and midwestern U.S., white-tailed deer are also known to carry ticks which serve as the primary vector for the bacteria *Borrelia burgdorferi* (Lyme disease). Human infections of Lyme disease in these areas have increased 25-fold since 1982 (DeNicola et al. 2000). Thus, high densities of deer pose a very real risk to human health, especially in the east and midwest where Lyme disease is prevalent.

Predation

Deer-vehicle collisions are the main source of white-tailed deer mortality in urban and suburban areas (Witham and Jones 1992, Etter et al. 2002, Porter et al. 2004). This problem has significant consequences, both in economic terms and with regards to human injuries (for more thorough review see Krausman et al. 2011). In rural areas hunter harvest is generally the primary source of deer mortality (Harden et al. 2005). In some situations, abundant white-tailed deer populations may draw large predators such as mountain lions into close proximity to human development. This can influence public perception of wildlife through perceived risk (Riley and Decker 2000, Hudenko et al. 2008).

Summary

White-tailed deer populations have expanded their range with the growth of suburban areas. Across their distribution, deer have proven highly adaptable to human activity. White-tailed deer often select high quality forage near residential structures and benefit from reduced predation rates and a lack of hunting in close proximity to human development. While white-tailed deer will respond to perceived threats with overt behavioral reactions and physiological changes, these behaviors do not appear to negatively impact demographics. In fact, white-tailed deer often have higher survival rates in urban environments (Swihart et al. 1995). However, evidence suggests that during sensitive periods of the year, such as during fawning, white-tailed deer tend to avoid human disturbance. In some situations, selection for areas near houses in winter may occur because no alternate undeveloped habitat exists in the region (Gill et al. 2001). In Montana, during the early stages of development, white-tailed deer use declined with increasing housing densities (Vogel 1989). This work suggests the need for more studies that examine how white-tailed deer respond to incremental development in high quality undeveloped habitat. Further, there are likely large behavioral differences between highly habituated white-tailed deer in the eastern United States and deer in the West, where large undeveloped spaces still exist. This highlights the need for future research that will increase our understanding of the impacts of residential development on western white-tailed deer winter range.

Although some people appreciate seeing deer in their neighborhoods, habituated white-tailed deer almost always create problems. White-tailed deer can have cascading and pervasive impact on residential communities through the spread of diseases, increased deer-vehicle collisions, attacks on humans and alterations to plant structure and plant community composition. Human attitudes and perceptions of white-tailed deer in urban environment can limit wildlife management options. Successful white-tailed deer management must include input from various stakeholders because management actions have the potential to take place in peoples' backyards. Thus, to maintain public confidence, managers must request input from the community (Cornicelli et al. 1993, Lauber 2010). White-tailed deer in the West are an important species both economically and culturally. Care should be taken to fully understand the effects of development on local populations before critical habitat is lost.

Table 4. Review of scientific literature on the effects of human disturbance on white-tailed deer, summarizing study authors, study duration, whether the study was peer reviewed or not, sample size, location, study area size, development type, study design, collar type, general methods and results, housing buffer, minimum patch size requirements and conclusions and management recommendations.

Author: *Study Duration*	**Peer Review**	**Sample Size**	**Location, Study area size**	**Development Type**	**Study Design**	**Collar Type**	**General Methods**	**General Results**	**Housing Buffer**	**Min patch size**	**Conclusions & Management Recommendations**
Etter et al. 2002: *1995-1998*	yes	n = 200 ET, 140 VHF	Chicago, IL; 3349 km^2	resid.	Obs.	VHF	Monitored VHF-collared and ear-tagged deer twice weekly, analyzed movement, home ranges and survival.	Survival was high compared to rural populations, the majority of deaths were caused by DVC, dispersal was ↓, HRs were ~= to other suburban populations.	na	na	Suburban deer have high survival rates which can cause ↑ populations. Management should take movements into consideration. DVC should be addressed.
Grund et al. 2002: *1996-1999*	yes	n = 31	Bloomington, MN; 30 km^2	resid.	Obs.	VHF	Monitored VHF-collared deer, analyzed movements and home range use.	HRs varied according to season, especially during a severe winter, HRs were smaller than those of rural deer.	na	na	Deer use habitat in and near residential areas especially during severe winters. Exurban deer can move seasonally and management should take the season of deer-human conflict into account.
Hurst & Porter 2008: *1960-70 & 2003-2004*	yes	na	Adirondacks, NY; na	resid.	Obs.	VHF	Monitored VHF-collared deer 3+x/week, compared historic to present winter yard locations, analyzed winter yard fidelity and migration patterns.	9 of 16 winter yards were relocated from historical to contemporary, 8 of 9 moved closer to residential area, 1 of 9 contracted yard around feeder. Deer migrated to same winter yards, but changed area a little.	na	na	Deer can change winter yards as migration is learned, not innate. Feeding deer (now illegal in NY) will bring deer closer to residential areas. Managers still need to work on limiting shrubs.
Hygnstrom & VerCauteren 2000: *1995-1997*	no	n = 59	Sarpy County, NE, na	resid.	Obs.	VHF	Monitored VHF-collared deer 4x/week, noted habitat and location.	Average HR was 276 ha, but almost half had much smaller, exhibited high fidelity to home range with little emigration even with high densities and hunting pressure.	na	na	Deer have ↑ densities and small HRs when living near suburban development, since emigration rates are ↓, deer effectively managed with hunting.
Kilpatrick & Spohr 2000a: *1995-1997*	yes	n = 25	Groton, CT; 1.9 km^2	resid.	Obs.	VHF	Monitored VHF-collared deer 1x/week for movements around suburban area.	No difference in HR during year, deer moved closer to resid. during bowhunting, average HR was smaller in developed than undeveloped, deer ≠ avoid development.	na	< 0.01 km^2	Deer are using residential area. Late season bow hunt should be implemented. Sharpshooting program should put out bait piles every 40-50 ha to ensure access to entire population.
Kilpatrick & Spohr 2000b: *1995-1997*	yes	n = 39	Groton, CT; 186.8 km^2	resid.	Obs.	VHF	Monitored VHF collared deer every 4 hours 1 day/week, found HR and CA size and number of houses in each during different seasons.	HR and CA size did not differ between seasons. More houses were in HR during winter than fawning season. Bird feeders provided food. Highest use near houses was in March.	na	0.09 undevel., 0.07 km^2 res. devel.	Local management is necessary. Remove birdfeeders. Management action most efficient during March when HR smallest and closest to houses.
Kilpatrick & Stober 2002: *1995-1997*	yes	n = 44	Groton, CT; 1.9 km^2	resid.	Obs.	VHF	Monitored VHF-collared deer, placed temporary bait piles, analyzed proximity to bait piles	Deer retained CA if bait site was placed within CA, shifted CA toward bait site if the site was within HR, but outside of core area, and abandoned CAs far from bait sites.	na	na	Baiting with hunting could affect deer within a 30-60 ha area since deer used the bait sites if they were within HR. Bait sites shouldn't affect deer whose HR do not include bait site.

Table 4 Cont.

Author: *Study Duration*	Peer Re-view	Sample Size	Location, Study area size	Devel-opment Type	Study Design	Collar Type	General Methods	General Results	Hous-ing Buffer	Min patch size	Conclusions & Management Recommendations
Piccolo et al. 2000: *1998-1999*	no	n = 21 (10 in Des Plaines and 11 in Palos)	Des Plaines and Palos Forest Preserves near Chicago, IL; na	resid.	Obs.	VHF	Monitored VHF collared deer day and night, but only collected ~14 locations. Used MCP to generate HR.	Des Plaines deer had smaller, more linear HR that stretched into urban areas outside the reserve. Palos deer remained within the preserve boundaries and had smaller more centralized HRs.	na	na	Des Plaines deer were forced into residential areas. Palos deer had smaller HR because food was more abundant. HR may expand when deer reach carrying capacity. Control might be necessary to preserve local plant communities and min deer human conflicts.
Porter 2004: *1997-1999*	yes	n = 22	Monroe County, NY; 43 km^2	resid.	Obs.	VHF	Monitored VHF-collared deer, modeled HR and fidelity, tracked survival, modeled population.	Most deer moved some seasonally, had 6-10% dispersal rates, small HRs compared to rural areas, main causes of death were DVC, hunting and accidents during culling.	na	na	Localized control though contraception and/or culling can work, but dispersal makes it complicated. Managers should consider removing deer from problem areas only.
Rhoads et al. 2010: *2004-2006*	yes	n = 66	Cecil County, MD: 23 km^2	resid.	Obs.	VHF	Monitored VHF-collared deer in all seasons, analyzed movements, HR, habitat use.	HR varied according to season, including hunting season, deer moved most in dusk, HR sizes approx same as other midwestern exurban populations.	na	na	Exurban deer populations exhibit tendencies between urban/suburban and rural populations, since they didn't exhibit a lot of movement, management strategies should be effective.
Storm et al. 2007a: *2003-2005*	yes	n = 43	Carbon-dale, IL; 18 km^2	resid.	Obs.	GPS, VHF	Monitored VHF and GPS-collared deer 2+x/week and every 1-2 hours, analyzed movements within landcover and distance to structures, mortality analysis.	HR size between rural and suburban ranges, tended (not statistically) to avoid structures during fawning. In winter, grassland outside of ZOI was preferred over grassland inside, but forested cover was preferred over entire site.	100m	na	Habitat use is generally in between suburban and rural. Main problem may be lack of hunting. Alternatives to hunting will be needed to manage deer herds if exurban development continues
Swihart et al. 1995: *varied between sites*	no	varied between sites	Carbon-dale, IL; 47 km^2, Chicago; 5900 km^2, Bethel-Newton, CT; 25 km^2, Bridge-port CT; 1.8 km^2	resid.	Obs.		Summarized Cornicelli 1992, Witham and Jones 1992, and analyzed unpublished data from Bethel-Newton CT and Bridgeport CT.	Deer avoided developed areas (> 80 houses/ km^2) and had smaller HR in urban areas. Activity was more concentrated in urban areas. Survival was approx. = between rural and urban areas. Deer browsed close to houses where spp richness was 2 x greater <50 m from houses.	none	na	Deer can habituate to urban areas. There are high densities of deer in urban areas because 1) low movement dispersal, 2) decreased human and non-human predation, 3) increased feeding by people. Need to find way to manage urban deer where hunting is difficult.

Table 4 Cont.

Author: *Study Duration*	**Peer Re-view**	**Sample Size**	**Location, Study area size**	**Devel-opment Type**	**Study Design**	**Collar Type**	**General Methods**	**General Results**	**Hous-ing Buffer**	**Min patch size**	**Conclusions & Management Recommendations**
Vogel 1989: *1981-1983*	yes	n = 12 VHF, n = 25 colored neckband	Gallatin Valley, MT; 1000 km^2	resid.	Obs.	VHF	Monitored VHF-collared deer every 1-2 weeks, analyzed movements and habitat use.	Deer used developed land less than undeveloped (80% deer observed white-tails). Closer to development HRs became smaller and more linear, and deer became more nocturnal. Housing was more detrimental when evenly distributed.	400m	na	Deer were less likely to be active when there were >11 houses within 800 m. Managers should cluster developments because the first houses in an area have the greatest effect.
Witham & Jones 1992: *1983-1989*	no	n = 103 live captures	Cook, DuPage, Kane, and Lake counties IL; 5,900 km^2	resid.	Obs.		Monitored deer population, reduced deer with sharpshooting, Measured vegetation pre and post deer removal, surveyed DVC.	Deer body condition varied between sites that were relatively close to each other. Some plant species seemed to regenerate after reduction in deer density.	na	na	Deer survival, age distribution, reproduction were similar to other studies on WT deer. Deer affected the plant community at high density. Lethal methods are needed to reduce deer abundance.

Notes: Abbreviations are ET, ear-tagged; DVC, deer-vehicle-collision; HR, home range; CA, core area; Obs., observational; resid., residential.

Mule Deer

Key Characteristics of winter range

Mule deer are important species both economically and socially in the American West (Geist 1998). Unlike white-tailed deer, mule deer do not occur in humid climates of eastern North America. However, their western range extends from the boreal forests of Canada to the arid deserts of Baja Mexico (Wallmo 1981). Winter habitat preferences, therefore, vary according to ecoregion, presence of trees or cover and snow depth (Watkins et al. 2007). In the Rocky Mountains, mule deer, like white-tails, are often migratory, moving from alpine environments in the summer to low-elevation valley bottoms in the winter, though some mule deer remain resident year-round (Nicholson et al. 1997). As with other ungulates, mule deer prefer areas with low snow depths (< 40 cm) and high solar duration in winter (D'Eon and Serrouya 2005, Poole and Mowat 2005). When snow depths increase they tend to prefer mature forests with high crown closures which intercept snow, provide thermal and security cover as well as important winter forage (Pac et al. 1991, Armleder et al. 1994, Baty 1995, Safford 2003, D'Eon and Serrouya 2005, Poole and Mowat 2005, Serrouya and D'Eon 2008, Proulx 2010). In open arid regions mule deer will often find cover in rugged topographic features such as coulees (Wood 1989, Fox et al. 2009). Areas of winter range that provide a diverse cover and browse when conditions are severe are considered critical as deer tend to congregate in them in high densities at certain times (Pac et al. 1991).

Mule deer are also opportunistic feeders and select similar forage to white-tailed deer, however, preferences vary regionally (Wallmo 1981). Studies indicate that the two deer species avoid competition through minimal spatial overlap (Baty 1995). In open habitat, shrubs such as sage brush are considered important browse when other forage is unavailable (Carpenter et al. 1979, Fox et al. 2009) while in forested habitats mule deer select many woody species (Hayden et al. 2008). Naturally cured forbs are also important winter browse (Geist 1998). Throughout the year, mule deer prefer diverse habitats with a range of species and cover types. Thus, invasive plants that create single-species vegetative cover, such as cheat grass (*Bromus tectorum*), decrease habitat quality for mule deer (Watkins et al. 2007). However, mule deer are also known to winter near irrigated agricultural areas and can cause extensive damage to hayfields, stackyards and orchards (Reed 1981). Because winter forage has low digestibility, mule deer often enter a negative energy balance in the winter, making fat and protein stores important determinates in overwinter survival (Torbit et al. 1985). In general, mule deer display high fidelity to home ranges and individual migration routes, but can shift distribution to accommodate changing environmental conditions (Pac et al. 1991, Nicholson et al. 1997, Sawyer et al. 2009b).

Response to Development

Mule deer exhibit a number of short-term overt behaviors in response to human activity. Mule deer alert to approaching humans at longer distances (70-1000 m) than white-tailed deer, likely a result of their adaptation to more open habitats (Lingle and Wilson 2001). Like other ungulates, mule deer display stronger responses to humans on foot than to vehicles. In Colorado, mule deer initially responded to snowmobiles at longer distances than hikers, but fled from hikers more frequently and for longer distances (191 m for hikers and 133 m for snowmobiles). However, disturbance trails did not have an impact on mule deer reproduction or survival though the authors estimated that each disturbance event cost between 0.2-5% of daily metabolic requirements (Freddy et al. 1986). In Antelope Island State Park, Utah, mule deer responded to hikers and mountain bikers with a 70% probability of flushing when within 100 m of trails. When recreationists were located off-trails their probability of flushing increased to 96% and did not drop to 70% until perpendicular distance from humans reached 390 m (Taylor and Knight 2003). However, Wisdom et al. (2004) found that radio-collared mule deer did not display an increased probability of flight in response to hikers, mountain bikers, horseback riders and ATVs in the Starkey Experimental Forest and Range in northeastern Oregon, where vegetation and hiding cover were likely higher than on Antelope Island. Movement rates did increase slightly to recreationist's presence, but not to ATVs (Wisdom et al. 2004).

Mule deer have been shown to avoid human development and roads in certain cases (Nicholson et al. 1997, D'Eon and Serrouya 2005). In north-central Colorado, winter pellet transects indicated that mule deer used habitat within 200 m of roads significantly less than areas farther from roads. This relationship was stronger in shrublands than in forested habitat (Rost and Bailey 1979). As with other ungulates, roads can produce a significant source of mortality through deer-vehicle collisions. Roads may also fragment populations and can alter migratory behaviors (Reed 1981, Hayden et al. 2008). In Colorado, Reed et al. (1975) video recorded mule deer attempting to cross an I-70 underpass not specifically designed for wildlife crossings. They found that mule deer had a 40% group success rate and 61% of individuals were eventually successful. This study was one of the first examinations of wildlife-highway mitigation efforts (Hebblewhite 2008).

Several studies have examined mule deer behavior and distribution in relation to residential development. As described in the white-tailed deer section, Vogel (1989) monitored deer response to development in the Gallatin Valley near Bozeman, Montana. During a period of rapid residential growth in the valley (53.4% increase in residents from 1970-80) residents reported that white-tailed deer populations had encroached on historic mule deer ranges. The study monitored both deer species (though 80% were white-tailed) and found that deer avoided houses and increased nocturnal behavior near subdivisions. Fewer houses were present within 800 m of mule deer observations than within 800 m of white-tailed deer observations, alluding to an increased avoidance of human disturbance by mule deer compared to white-tailed deer. As discussed earlier, future studies with larger sample sizes are needed to confirm the results of this research. In Shasta County, California, winter pellet transects around 15 houses in a residential subdivision indicated that deer use was lower within 22.8-45.7 m of houses compared to areas > 68.6 m from houses. The authors suggest that deer habitat use was influenced up to 82.3 m from houses during the winter (Smith et al. 1989). McClure et al. (2005) monitored VHF-collared mule deer on two different winter ranges in the Cache Valley of northern Utah. They found that deer that wintered in an urban area (15-800 houses/km^2) were more likely to be migratory, and migrated earlier in the spring, than deer on a rural winter range. Urban deer also exhibited lower fawn recruitment (measured through fawn:doe ratios) even though migratory animals from the two herds intermixed on a common, high-elevation summer range. Urban deer had smaller home ranges and selected concealment vegetation, which may have limited forage opportunities and account for the difference in fawn survival, though the mechanisms driving the differences between urban and rural deer were not specifically tested (McClure et al. 2005).

A series of studies on mule deer response to energy development in the Jonah and Pinedale Anticline natural gas formations in southwest Wyoming demonstrate that mule deer avoid a wide range of human developments including roads and infrastructure associated with oil and gas development. Hebblewhite (2008) summarized the Sublette mule deer studies in an extensive review of the effects of energy development on ungulates. Early publications indicated that mule deer exhibited strong behavioral avoidance of well pads and roads (avoidance up to 2700-3700 m of well pads; Sawyer et al. 2006, Sawyer et al. 2009a). However, the two final reports of the study: Sawyer et al. (2009c) and Sawyer and Neilson (2010), that monitored mule deer response over 10 years of energy development, were the first to document population-level declines. Though the results continue to be preliminary, the 9-year trend in abundance suggests a 36% decline since 2001. Further, four years of population surveys of a nearby herd outside the energy development area have displayed increasing abundance during the same time-frame. These results are some of the first, from long-term monitoring projects, that imply development pressure can have negative population impacts on mule deer.

Habituation

Similar to white-tailed deer, mule deer populations can exceed human tolerance in suburban and urban areas. In some areas mule deer browsing at high densities can cause substantial damage to crops, orchards and ornamental vegetation near homes (Reed 1981). Some evidence suggests that mule deer do not adapt as well as white-tailed deer to residential areas (Vogel 1989, McClure et al. 2005), but high densities of mule deer have been documented in urban areas, such as Helena, Montana (Hickman 2007). As with white-tailed deer, managing urban populations of mule deer requires education and outreach to the public as well as input from various stakeholders on management and control options.

Migration

In the Rocky Mountains, a large percentage of mule deer are migratory, moving 20-158 km between seasonal ranges (Brown 1992, Sawyer et al. 2005). However, many populations contain both resident and migratory deer, suggesting that migration strategies are adaptive and can vary depending on environmental stochasticity, predation pressure and individual costs associated with migration (Kufeld et al. 1989, Pac et al. 1991, Brown 1992, Nicholson et al. 1997). In southern California, migratory female mule deer tended to avoid human development more than non-migratory deer and exhibited high plasticity in migratory patterns (Nicholson et al. 1997). Other studies have also found high life-long fidelity to migration behaviors and traditional routes, and suggest that early learning by fawns form perpetual movement patterns (Pac et al. 1991, Sawyer et al. 2009b). Thus the protection of migration routes is essential for the maintenance of many ungulate populations (Berger 2004).


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Unfortunately, migration corridors can be negatively impacted by even small amounts of development. Between 2,500–3,500 mule deer moved through the Trappers Point bottleneck, a natural topographic feature in Wyoming that funnels ungulate movements between summer range in the Yellowstone and Jackson Hole regions and winter range in the Green River valley. Threats such as residential development, roads and fences have reduced the passage by almost half its original width. Any increase in development has the potential to significantly affect mule deer migrations. In southwest Wyoming, Sawyer et al. (2009b) and Sawyer and Kauffman (2011) used statistical movement models to identify stop-over sites along mule deer migration routes. Mule deer spend 95% of their time at stop-over sites during migrations to forage and amass additional energy reserves. The authors found that these sites had higher quality forage than migration corridors and suggest that stop-over sites should have high conservation priority because of their importance to maintaining migratory behavior (Sawyer and Kauffman 2011). They also found that while individual mule deer displayed strong fidelity to migration routes, the subpopulation used a network of migration corridors between seasonal ranges. Managers should consider prioritizing routes that are used by a larger proportion of the population over routes used by only a few individuals (Sawyer et al. 2009b).

Disease

Mule deer can contract multiple rapidly spreading diseases such as tuberculosis, hemorrhagic disease and CWD (Mule Deer Working Group 2003). Chronic wasting disease is especially pertinent to mule deer populations because studies have shown that rates of infection are higher in mule deer than in white-tailed deer and other ungulates (Habib 2010). Symptoms of CWD include weight loss, loss of fear of humans, and ultimately degradation of brain matter. It is of special concern for its similarity to livestock diseases and potential for cross-species infection (Mule Deer Working Group 2003). A study in Colorado found that CWD infection increased with proximity to developed areas; potentially due to the high densities and more sedentary nature of deer in urban areas (Farnsworth et al. 2005). Further, urban areas may have lower predation rates from natural and human hunters allowing infected deer to live longer and shed more infectious agent into the environment. A recent study modeled CWD disease transmission and found that selective predation on diseased prey (mimicking wolf predation on deer) reduced disease prevalence much more rapidly than nonselective mortality (Wild et al. 2011). Thus, predators may be an important management tool in reducing the risk of CWD in deer.

Predation

The influence of predation by coyotes, mountain lions, and wolves on mule deer populations depends on many interacting factors such as habitat quality, the influence of human development, climate, competition with other ungulates and a range of other environmental dynamics (Ballard et al. 2001). Few studies have determined clear consequences of predation on mule deer populations (Gill 1999). In some areas hunting can play a large role in regulating populations. However, more studies are needed to determine how human development, especially exurban residential development, interacts with predation rates to influence mule deer populations in the West.

Summary

Mule deer population levels are well below historic highs recorded in the 1940's, likely due to synergistic factors such as loss of high quality habitat as a result of increased human development, competition with other ungulates and livestock, predation, over-hunting in some areas and disease (Gill 1999). While studies that isolate these confounding and interacting influences are lacking, it is probable that human development has played a large role in mule deer declines in the West. Mule deer are known to react behaviorally to human activity and recreation. In some cases, avoidance of human disturbance increases energy expenditure and could impact individual survival during the winter when travel is difficult. However, other studies have shown that mule deer may not always flee from approaching humans and more research is needed to elucidate these discrepancies.

In general, mule deer avoid human developments. Habitat use has been shown to be lower around roads and other industrial infrastructure such as well sites. Residential development probably has a serious impact on mule deer winter range, especially when it impacts undeveloped areas. Pellet transects indicate that mule deer use areas near houses less than areas farther from houses in winter. Further, urban areas may affect migration strategies and have been shown to decrease fawn recruitment, thought the mechanisms driving these differences require further study. A series of long-term studies (>10 years of monitoring) on the effects of oil and gas development have indicated that mule deer populations are declining in response to large scale energy development in southwest Wyoming. These studies are the first of their kind to begin to shed light on large-scale ungulate responses to development and suggest that demographic impacts may take many years to detect (Sawyer and Neilson 2010).

Because mule deer utilize flexible migration behaviors to maximize resources and possibly decrease predation pressure, protecting migration corridors should be a high conservation priority. Important stop-over sites along corridors also merit protection. Like white-tailed deer, mule deer can also become habituated to urban areas. Deer populations can pose a threat to human safety, cause property damage and high densities of deer can generate concerns for animal welfare (Hickman 2007). Other indirect effects of development include an increase in the transmission rate of CWD. Future research is needed to determine how predation, disease and residential developments may interact to influence mule deer populations.

Table 5. Review of scientific literature on the effects of human disturbance on mule deer, summarizing study authors, study duration, whether the study was peer reviewed or not, sample size, location, study area size, development type, study design, collar type, general methods and results, housing buffer, minimum patch size requirements and conclusions and management recommendations.

Author: *Study Duration*	**Peer Review**	**Sample Size**	**Location, Study area size**	**Development Type**	**Study Design**	**Collar Type**	**General Methods**	**General Results**	**Housing Buffer**	**Conclusions & Management Recommendations**
D'Eon & Serrouya 2005: *1999-2003*	yes	n = 12	Selkirk Mountains, BC; 219.24 km2	roads	Obs.	GPS	Monitored GPS-collared mule deer every 4-6 hours, created RSF for winter and summer at 2nd order scale.	In winter deer preferred ↓ elevations, ↑ solar duration, mature fir-pine forest, ↑ crown closures, avoided cedar, hemlock and early seral. Some deer avoided roads (6 of 12 used locations farther from roads than random).		Elevation and solar duration are best determinates of winter range. Protect mature forest in winter range and keep roads out of winter range.
Farnsworth et al. 2005: *1997-2002*	yes	na	Larimer County, CO; 1200 km2	resid.	Obs., Modeling		Tested deer for CWD in urban and rural areas, modeled results.	Males had almost double the infection rate of females, urban deer had almost double the infection rate of rural deer, different sites had varying levels of infection.		Prevalence may be ↑ in urban areas because of increased sedentary behavior, fewer predators (infected deer lived longer) and concentration due to habitat loss. Urban deer need to be managed when trying to control CWD.
Freddy et al. 1986: *1979-1980*	yes	n = 17 collared (VHF or neck-band), 67 trials	North-central CO; 3 km2	recreat.	Obs., Compar.	VHF	Compared flight responses of mule deer to approach trials by snowmobiles and hikers.	Responses by deer to hikers were longer in duration, involved running more frequently, and were greater in estimated energy expenditure. Each disturbance event cost 0.2-5% of the daily metabolic requirements.		Minimizing all levels of response by deer would require persons afoot and snowmobiles to remain >334 m and >470 m from deer, respectively. Human activity restrictions required on winter ranges.
Gill et al. 1999: *na*	no	na	Colorado; na	all	Review		Reviewed literature and historical trends. Evaluated different hypotheses for mule deer declines in Colorado.	Declines could be caused by; 1) competition with increasing elk populations, 2) density dependence, 3) long-term declines in habitat quality, 4) overharvest in some key areas, 5) increasing predator populations, and 6) diseases.		Recommended large-scale adaptive management experiments designed to test the main hypotheses of predation and habitat change. Long-term (6-8 year), large-scale (WMU scale, 1000 km^2) will be required to rigorously assess mule deer declines.
Kufeld 1989: *1982-1984*	yes	n = 27	Rocky Mountain Front, CO; 14.5 km2	Hunting	Obs.	VHF	Monitored VHF-collared deer 1x/10 days, noted location.	25/27 deer were resident and exhibited high fidelity to home range, even when hunted.		Mule deer in CO can be migratory or non-migratory, especially in areas with high quality winter and summer habitat. Resident and migratory deer herds should be managed in sub-units.
McClure et al. 2005: *1994-1995*	yes	n = 17 urban, 14 rural	Cache Valley of northern UT; 32 km2 urban, 42 km2 rural	resid.	Obs., Compar.	VHF	Monitored VHF-collared deer 2-3x/week, monitored migratory status and number of fawns for both rural and urban deer.	15 of 17 urban deer were migratory, opposed to 8 of 14. Deer in urban areas travelled an average 31.5 km and deer in rural areas travelled an average 14.5 km between winter and a shared summer range. Urban deer had lower fawn recruitment than rural deer.		Available forage was similar between rural and urban. However, risk differed and urban deer had smaller home ranges. Urban deer behavior to avoid risk may have limited forage opportunities and may account for the difference in fawn survival.

Table 5 Cont.

Author: *Study Duration*	**Peer Review**	**Sample Size**	**Location, Study area size**	**Development Type**	**Study Design**	**Collar Type**	**General Methods**	**General Results**	**Housing Buffer**	**Conclusions & Management Recommendations**
Nicholson et al. 1997: *1989-1991*	yes	n = 23	San Bernardino Mnts, CA; 320 km2	develop.	Obs.	VHF	Monitored VHF-collared deer every 10 days, analyzed results for habitat selection and survival.	14 migrated, 4 switched, 5 were resident, all exhibited high fidelity to home range. Avoided development in all seasons. Migratory animals used ↑ quality habitat and were farther than expected from development. During low precip. years migratory had ↑ mortality.		Deer exhibit behavioral plasticity, dual strategies probably exist because of higher predation risk during migration.
Reed et al. 1975: *1972-1973*	yes	n = 4450 video approaches	Eagle County, CO; na	roads	Obs.		Video-taped mule deer responses to a concrete box underpass under I-70 in Colorado.	Mule deer groups had a 40% success rate, 60% overall individual success.		Underpasses can be useful to mitigate negative effects of habitat fragmentation and mortality caused by roads – first study of its kind.
Rost & Bailey 1979: *1973-1974*	yes	n = 66 sites	Roosevelt and White River NFs, CO; na	roads	Obs.		Transects for abundance and density of fecal pellets at sites along roads.	Deer and elk avoided roads, particularly areas within 200 m of a road.		Expanding road systems will effect distribution of elk and deer. Range improvement projects would benefit deer and elk more if they were located away from roads.
Sawyer et al. 2005: *1998-2001*	yes	n = 171 (27 GPS, 144 VHF)	Western WY, 15000 km2	energy extraction, resid.	Obs.	VHF, GPS	Monitored VHF and GPS-collared mule deer along migration routes. VHF collared animals were monitored every 7-10 days during migration.	Mule deer migrated 20-158 km between seasonal ranges. A number of significant bottlenecks were observed. Estimate 2,500–3,500 mule deer moved through the bottleneck twice a year.		Housing developments have narrowed effective bottleneck to <0.8 km. Fences, roads, and ↑ human disturbance influences the effectiveness of mule deer migration routes. Special attention should be paid to migration routes especially where bottlenecks occur.
Sawyer et al. 2006: *1998-2003*	yes	n=77 (45 VHF '98-00, 7-15 GPS/yr '00-03)	Pinedale Anticline Project Area, southwest WY, ~800 km2	energy extraction	Obs., Compar.	VHF, GPS	Monitored VHF collared deer every 7-10 days 1998-2000, GPS deer monitored every 1-2 hrs 2000-2003. Modeled habitat selection before and during development.	Mule deer avoided areas in close proximity to well pads. Changes were immediate (i.e., year 1 of development), and no evidence of well-pad acclimation. Lower predicted probabilities of use within 2.7 to 3.7 km of well pads.		Indirect habitat losses larger than direct habitat losses. Some areas classified as high probability of use before development changed to areas of low use after development and vice versa. Higher densities of well pads will negate the potential effectiveness of timing restrictions on drilling activities.
Sawyer et al. 2009a: *2005-2007*	yes	n = 31	Pinedale Anticline Project Area, southwest WY; ~800 km2	energy extraction	Obs.	GPS	Monitored GPS collared mule deer every 2 hrs. Examined mule deer response to 3 types of well pads and modeled resource selection.	Mule deer avoided 2.61 km from LGS well pads, 4.30 km from non-LGS well pads, and 7.49 km from active drill pads and selected areas further from well pads with high levels of traffic in winter.		Impacts could be reduced through technology and planning that min. the number of well pads and human activity. LGS pipelines ↓ long-term indirect habitat loss, whereas drilling in crucial winter range created a short-term ↑ in deer disturbance and indirect habitat loss.

Table 5 Cont.

Author: *Study Duration*	Peer Review	Sample Size	Location, Study area size	Development Type	Study Design	Collar Type	General Methods	General Results	Housing Buffer	Conclusions & Management Recommendations
Sawyer et al. 2009b: *2005-2006*	yes	n = 44 GPS, 80 migrations	Southwest WY; winter ranges; 40 & 141 km2	energy extraction	Obs.	GPS	Monitored GPS-collared deer every 2.5 hrs, created a movement model to find migration corridors and stopover site, >10% use = corridor.	3 main migration corridors for Wild Horse range and 1 for Dad range. Individual mule deer displayed strong fidelity to migration routes, the subpopulation used a network of migration corridors.		Important to conserve migration routes in area with impending development. Suggest stopover sites should have high conservation priority. Prioritizing routes that are used by a larger proportion of the population over routes used by only a few individuals
Sawyer et al. 2009c and Sawyer & Neilson 2010: *1998-2010*	no	n > 360 GPS and VHF	Pinedale Anticline Project Area, southwest WY; ~800 km2	energy extraction	Obs., Compar.	VHF, GPS	Monitored GPS and VHF collared mule deer in treatment and reference areas pre-development and during development of oil and gas infrastructure.	9-year trend during development suggests a 36% decline since 2001. 4 years of population surveys of a nearby reference herd displayed increasing abundance during the same time-frame.		Mule deer continued to avoid areas close to well pads in years 8, 9 and 10 of development. Recommend abundance be measured directly, rather than estimated from survival rates. Use of LGS can reduce traffic levels and the amount of indirect habitat loss, which may minimize the potential negative effects on survival.
Smith et al. 1989: *4 months 1983*	no	n = 114 transects	Shasta County, CA; 132 km2	resid.	Obs.		Counted pellets along transects near 15 houses.	Deer use was less 22.8-45.7 m from houses than > 68.6 m. Deer use was influences up to 82.3 m from houses during winter.	82.3 m	Deer avoided houses. There appeared to be a tendency for deer to avoid houses with dogs more. Deer also tended to use areas closer to homes that were surrounded by dense cover.
Taylor & Knight 2003: *2000-2001*	yes	n= 110 obs.of on-trail mule deer, 60 off-trail	Antelope Island, UT; 104 km2	recreat.	Obs., Survey		Observed ungulate response to humans, surveyed recreationists.	Mule deer exhibited a 70% probability of flushing from on-trail recreationists within 100 m from trails and 96% probability of flushing within 100 m of recreationists located off trails. Probability of flushing did not drop to 70% until perpendicular distance reached 390 m.		Wildlife is being affected by recreation more than people realize. Need to ↑ public education, limit off-trail use and trail use during calving/fawning. Enforce buffer zones around wildlife.
Vogel 1989: *1981-1983*	yes	n = 4 VHF, 5 colored collar	Gallatin County, MT; 1000 km2	resid.	Obs.	VHF	Monitored VHF-collared deer every 1-2 weeks, analyzed movements and habitat use.	Fewer houses were present within 800 m of mule deer obs. than within 800 m of white-tails. Deer use decreased curvilinearly as development increased - the first few houses had the greatest effect. Shift in spp composition from mule deer to white-tailed deer.	400 m	Potential increased avoidance of human disturbance by mule deer compared to white-tailed deer. Deer were less likely to be active when there were >11 houses within 800 m. Managers should cluster developments because the first houses in an area have the greatest effect.
Wisdom et al. 2004: *2002-2004*	no	n = 12	Starkey, OR; 14.53 km2	recreat.	Exper., Compar.	VHF	Monitored VHF-collared deer every 10 minutes during treatments of off-road ATV, horseback riding, mountain biking and hiking.	Deer did not react as strongly as elk, slightly higher movement rates in response to all but ATVs.		Deer did not respond as strongly as elk to off road recreational activities. Deer might have changed fine scale behavior, such as moving short distances to dense cover. Suggest limiting off-road recreation.

Notes: Abbreviations are LGS, liquids gathering systems; CWD, chronic wasting disease; Exper., experimental; Obs., observational; Compar., comparative; recreate., recreation; resid., residential.

Elk

Key Characteristics of winter range

Elk once ranged across North America, but hunting and habitat loss resulted in their extirpation from the eastern portions of their range (Laliberte and Ripple 2004). In the West, elk occur in a large variety of habitats from open, desert valleys to the dense coastal, coniferous rainforests of the Pacific Northwest as well as a wide range of shrub, forest and prairie habitats. Adaptations to specific regions make winter range an inherently diverse and at times incongruous concept that requires site specific research to define (Toweill and Thomas 2002). Elk are often migratory in the Rocky Mountains, initiating movement to areas with less snow when snow depth reaches ~ 40 cm and utilizing low elevation south-facing slopes with low snow depths in winter (Poole and Mowat 2005). Snow depth exceeding 70 cm requires plowing or bounding and restricts elk movement (Sweeney and Sweeney 1984). Determining the exact space requirements of winter range for elk is difficult because quality of forage, snow accumulation and other factors such as predation, wind and competition with other ungulates and cattle all affect the area and location of winter range. For example, elk require smaller winter range in areas with lower snow depth and high quality forage biomass than in areas with low quality habitat (Anderson et al. 2005).

In the Rocky Mountain West, elk tend to prefer edge habitats where both browse and protective cover are available (Safford 2003). They are, however, highly adaptable and can use a wide variety of habitats including mesic meadows, xeric shrublands and forests and wet shrub meadows (Hobbs et al. 1982). Elk winter diet is flexible and will change according to the severity of winter and availability of forage (Hobbs et al. 1981). In less severe winters elk strongly prefer grazing to browsing but will paw through the snow for graminoids when they are sticking through the snow (Sweeney and Sweeney 1984, Baty 1995, Christianson and Creel 2007). When snow depth is high, or when graminoids are not available, elk will utilize high-protein shrub browse (Hobbs et al. 1981, Hobbs et al. 1982). Elk will also forage on hay bales in agricultural areas during periods of deep snow (Safford 2004). During periods of severe weather elk may opt for energy conservation over forage intake. Therefore, thermal cover is often necessary in high quality elk winter range (Christensen et al. 1993). In areas without forest cover, elk utilize low-elevation south-facing slopes with a high diversity of vegetation types and species (Sawyer et al. 2007). Despite generalist foraging habits, elk in the Greater Yellowstone Ecosystem steadily lose body mass and fat through the winter, which can affect pregnancy rates (Cook et al. 2001, Cook et al. 2004).

Response to Development

Elk response to development can be measured on a continuum from individual behavioral responses to population-level impacts. Many studies have demonstrated short-term behavioral changes as a result of human activity. In a controlled study within the Starkey Experimental Forest and Range in northeastern Oregon, elk were subjected to disturbance from off-road recreationalists. Radio collared elk responded most strongly to all-terrain vehicles (ATVs) and initiated flight at relatively far distances (> 1000 m, Preisler et al. 2006). Elk movement rates were also higher following disturbance by mountain bikers, horseback riders and hikers than during control periods of no human activity (Wisdom et al. 2004). Increased human recreation, both motorized and non-motorized, in elk winter range has been shown to increase the levels of stress hormones, especially when the recreation is sporadic (Cassirer et al. 1992, Creel et al. 2002). Vehicle use on roads also induced a physiological stress response in elk but was highest during the summer (Millspaugh et al. 2001).

More permanent development initially causes more drastic changes in elk behavior than sporadic recreation. The response of elk to roads and infrastructure was not extensively reviewed here, but some inferences relevant to residential development can be made about the impacts of industrial infrastructure on elk behavior and populations. Many studies have examined the various effects of roads on elk (Lyon 1979, Rost and Bailey 1979, Lyon 1983, Cole et al. 1997, Rowland et al. 2000, Cole et al. 2004, Ayotte et al. 2006, St. Clair and Forrest 2009). In general, avoidance of roads is greater in areas that experience hunting activity (Hillis et al. 1991, Hurley and Sargent 1991, Leptich and Zager 1991, Rumble et al. 2005), however these impacts can be mediated by many factors including habitat quality, topography and the spatial design of road networks (Edge and Les Marcum 1991). For example in heavily developed areas of Alberta, elk were more likely to occur in areas ≤ 0.5 km of road/km^2. With increasing road densities, elk tended to use areas near roads more often, most likely due to the decreasing availability of areas without roads. However, when road densities reached >1.08 km of road/km^2, elk displayed strong avoidance of roads and the design of the road network accounted for differences in risk of mortality (Frair et al. 2008). The avoidance of roads was likely due to risk associated with hunting in the region, as other studies have found that elk use areas with > 2 km of road/km^2 in areas where human activity is non-lethal and highly predictable such as Banff National Park (Hebblewhite et al. 2005).

In a thorough review of the effects of energy development on ungulates, Hebblewhite (2008) found that while the literature is lacking rigorous studies that examine population level responses to development, in general elk tend to avoid roads by 200 – 2000 m and active gas and well sites by 500 – 2000 m (Hebblewhite 2008:86). In Wyoming, avoidance distances around well sites was lowest in winter (500 m), but increased to up to 2000 m during the summer (Powell 2003). Similarly in southwestern Wyoming, Sawyer et al. (2007) found that during winter elk habitat use shifted closer to roads than in summer, likely a result of the lower levels of traffic during winter. Finally, the 2008 review also synthesized a series of long-term studies as part of the Montana Cooperative Elk-Logging study on the responses of elk to logging, human recreational disturbance and climate. This research, as well as more recent work conducted at the Starkey Experimental Forest and Range, suggests that elk avoid active logging, recent burns and roads (Hebblewhite 2008). However, without direct negative pressure from humans, elk can and will habituate to high levels of human disturbance and infrastructure (Thompson and Henderson 1998).

Population-level impacts of human development are expressed through altered distribution, abundance and vital rates. In Colorado, the expansion of the Vail ski area initially caused dramatic decrease in the number of elk observed in the area, especially where a chairlift was built (Morrison et al. 1995). By the end of the study, elk began to habituate to the development, but elk use remained low in areas where human activity was highest indicating that long term impacts may exist. To test the impacts of spring and summer recreational pressure in and around calving grounds, Phillips and Alldredge (2000) monitored 71-85 elk/area/year near the Vail ski area. Their results indicated that reproductive success and calf survival decreased during years of disturbance suggesting a significant impact on population growth. A follow-up study indicated that the herd was able to rebound after the disturbance pressure was lifted, though productivity did not exceed pre-disturbance levels (Shively et al. 2005).

Few studies have specifically examined the effects of residential development on elk. Subdivision development generally results in new infrastructure such as buildings and roads that directly reduce available habitat. Residential development also leads to greater human recreational use which can increase stress and vigilance in elk. In Colorado, habitat fragmentation as a result of housing developments and associated road and infrastructure construction caused elk to avoid patches of habitat less than 0.04 km^2. Elk prefered habitat patches greater than 0.24 km^2 with available hiding cover (Wait and McNally 2004). Housing development also affects elk movement patterns. In a residentially developing area north of Missoula, Montana, elk started moving faster 750 m from houses and trails and preferred habitat 1600 m from any human development (Cleveland 2010).

Habituation

Elk are a generalist species with the ability to adapt to a wide-range of habitats, including areas of human development. The degree of habituation varies according to habitat-type, the presence of predators and type of development (Stankowich 2008). According to Thompson and Henderson (1998), the risk of habituation is highest in winter and in areas with constant human pressure such as near town sites and housing developments. High elk population densities can also cause dispersal toward development which can lead to reduction or loss of migratory behavior, which may result in overgrazing of winter ranges by resident elk during summer (Thompson and Henderson 1998, Hebblewhite et al. 2006). A lack of hunting


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pressure is one of the key factors influencing the habituation of elk. Human development and activity can act as a "human shield" by reducing the risk of predation from both native predators and human hunters in areas close to development or in National Parks (Berger 2007). For example, in Alberta, near Banff National Park, elk that occurred within the townsite of Banff had significantly higher survival and recruitment than elk in the surrounding area. Elk density was also higher indicating that use of developed areas can be highly profitable for elk (Hebblewhite et al. 2005). Similarly, in Rocky Mountain National Park of Colorado, human disturbance had little effect on the distribution, abundance or behavior of elk. In fact, elk were frequently seen feeding during crepuscular periods in residential areas in the National Park and throughout suburban lawns and gardens of nearby Estes Park, Colorado (Schultz and Bailey 1978).

Urban elk populations are associated with a range of ecological and management problems such as crop depredation, overgrazing, property damage, injury to humans and increased risk of elk-vehicle collisions (Walter et al. 2010). However, human perception of the risks associated with habituated elk can be contradictory and in some cases can limit management options. In Flagstaff, Arizona, the majority of residents surveyed enjoyed seeing elk and were not concerned about safety issues. They did, however, express concern about lethal management methods (Lee and Miller 2003). Sporadic human activity and hunting pressure can reduce habituation (Thompson and Henderson 1998), but is not always possible due to societal values. In Banff, predator-resembling aversive conditioning with herding dogs and with humans with fire-crackers reduced habituation behavior. However, more effort is needed when predators are present outside of the developed area (Kloppers et al. 2005). Multiple non-lethal management strategies for limiting elk herds in and around developed areas exist, but many are under-examined, costly and energy-intensive (Walter et al. 2010).

Migration

Migratory behavior of ungulates is likely in decline worldwide as a result of habitat loss and fragmentation (Berger 2004). Elk are generally migratory in areas with large topographic relief and where snow depths influence forage availability in winter. Winter range enhancement, including feeding grounds and hunting restrictions, combined with predator relief can alter elk behavior from migratory to residential. In Alberta, near Banff National Park, the Ya Ha Tinda elk herd has decreased migratory behavior by 75% between 1970 and 2004. Further, the timing of migration has also shifted with elk returning to winter range almost a month earlier (Hebblewhite et al. 2006). Behavioral shifts in seasonal migration patterns have the potential to alter traditional predator-prey relationships, density-dependent population dynamics and jurisdictional management policies.

Disease

When elk congregate in large groups, as is common on winter range, they are more likely to contract diseases such as brucellosis and CWD (Olsen 2010). Rates of disease are generally higher in elk that congregate in areas with artificial feed, which is also where spread of the disease to cattle is most likely (Olsen 2010). Cross et al. (2010) found that although rates of brucellosis were initially higher in elk that utilized artificial feeding areas, the rates increased to elk that did not use feeding areas as well, potentially due to large group size rather than overall density. Development infringement on winter range could cause greater congregations of elk on remaining intact habitat or increase the density of urban elk habituated to the developed area.

Predation

As a prey species, elk react behaviorally to hunting pressure from both natural predators and from humans. Predators, such as wolves, tend to avoid areas of high human activity, therefore human developments can become a refuge for elk. In fact, in Banff National Park predation rate by wolves on elk was reduced by 60% where human activity was highest (Hebblewhite et al. 2005). Since humans do not hunt elk in national parks, resident elk could minimize predation risk by utilizing habitat near human settlements (Hebblewhite and Merrill 2009).

As discussed earlier, hunting also has profound impacts on elk behavior. Elk regularly hunted by humans exhibited more vigilance behavior than non-hunted elk and vigilance decreased after hunting season (Cleveland 2010). In areas of low road density and therefore less hunter access, bull elk survival doubled compared to areas with high road density (Christensen et al. 1993). Elk, will use areas with higher density roads in non-hunted areas than in areas with hunting (Frair et al. 2008). Elk also react to hunting pressure by moving to areas with hunting restrictions, including private lands (Burcham et al. 1999). With the increasing transfer of valley bottom lands from hunter-friendly ranches to seasonal hobby mini-ranches and exurban subdivisions, more land is available as a refuge for elk during the fall. This reduces the ability of managers to control elk populations further escalating problems with habituation (Haggerty and Travis 2006).

Summary

The main requirement for elk winter range is sufficient forage to provide a positive energy balance. European settlers initially used elk winter range as grazing range for domestic livestock and altered the natural vegetation structure (Toweill and Thomas 2002). Today, developers are creating exurban subdivisions on elk winter range. Because of the settlement patterns in the West, very little low-elevation land is designated as wilderness and therefore, there is a growing need to develop protocols to protect winter range. Because elk winter range varies from rarely grazed allotments to developed residential areas, the threshold between ‘wild’ and ‘non-wild’ range may be somewhat indistinct.

More studies are needed to determine the difference between functional and non-functional winter range. Determining how elk responses to development vary across a gradient that includes initial road construction to permanent infrastructure and the increase in human recreation that follows, can help augment our understanding of the impacts of residential development on elk. Initially, elk react to human disturbance with increased vigilance, flight and behavioral avoidance, all of which have the potential to increase energy expenditures. In northern climates, decreases in energy reserves can lower survival for both calves and adults. Therefore, development has the potential to lead to severe population level declines in elk. Unfortunately, very few studies have directly examined the population-level consequences of any form of human development on elk. Further, the overall influence of development depends on placement and spatial pattern of new residences across a gradient of habitat quality. The proximity to forests and escape and hiding cover, as well as landcover type, can all modify the effect of development. Other factors such as the presence of predators, the occurrence of hunting by humans and competition with other ungulate populations also have a significant impact on observed responses (Baty 1995, Jenkins et al. 2007). The minimum patch size of winter range in which elk can both avoid risks associated with human development and maximize fitness also depends on these same factors. Development that maintains open space by clustering structures in one part of a parcel is likely a first step towards minimizing conflicts with wildlife (Wait and McNally 2004).

Since much development itself is not actually lethal to elk, habituation is likely to continue to occur across the West. Elk are generalists and can subsist on a varied diet which includes graminoids and shrubs found in and around human development. Habituated elk are often found at greater densities than elk outside of development which can lead to faster spread of disease. Higher quality forage and an absence of predators can also lead to an elimination of migratory behavior. Resident habituated elk herds can create multiple problems in human communities. Because natural predators do not generally habituate as often as prey species and hunting by humans is often discouraged around development, management options are reduced. Habituated elk populations can create human-wildlife problems akin to white-tailed deer in the eastern United States.


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Table 6. Review of scientific literature on the effects of human disturbance on elk, summarizing study authors, study duration, whether the study was peer reviewed or not, sample size, location, study area size, development type, study design, collar type, general methods and results, housing buffers and conclusions and management recommendations.

Author: *Study Duration*	**Peer Review**	**Sample Size**	**Location; Study area size**	**Development Type**	**Study Design**	**Collar Type**	**General Methods**	**General Results**	**Housing Buffer**	**Conclusions & Management Recommendations**
Cleveland 2010; Chpt 2: *2008-2009*	no	n = 363 (obs.)	MT and WY; na	hunting	Obs.		Surveyed vigilance at 4 sites with varying levels of predation risk from human and non-human predators.	Vigilance ↑ with predation risk, ↓ vigilance in non-hunted herd (Mammoth, WY). Humans > impact on vigilance than non-humans (wolves), movement didn't ↓ after hunting season but vigilance did ↓	na	Humans influence vigilance. Elk have measured spatial and temporal response to hunting. Hunting, or non-lethal aversive tactics, can ↓ habituation. Managers should restructure hunting seasons to alter vigilance/movement.
Cleveland 2010; Chpt 3: *2007-2009*	no	n = 9	North Hills, Missoula, MT; na	resid.	Obs.	GPS	Monitored GPS-collared elk every 6 hours, modeled movement, first passage time (FPT) and habitat selection (RSF).	Hunting ↓ movement, but did not affect selection. Elk moved faster 750 m from houses and trails, selected habitat 1600 m from human development.	1600 m	Hunting effects habituation if elk perceive humans as risk, movement was related to human predation risk. Hunting is important to maintain a 'wild' elk herd and avoid habituation.
Creel et al. 2002*: 1998-1999*	yes	n = 125 (elk scat)	Yellowstone, Isle Royale, Voyageurs NPs; varied	recreat.	Obs.		Tested fecal GC levels in elk in Yellowstone and in wolves in Isle Royale, Yellowstone and Voyageurs.	GC levels increased in both species when snowmobile use increased, more than for wheeled vehicles.	na	Snowmobile season causes GC levels to increase, but did not cause a measurable effect on population. The impact could be more subtle and long term. Stress levels can indicate problems before demographic impacts occur.
Frair et al. 2008: *2001-2004*	yes	n = 23	AB, Canada; 2800 km^2	roads	Obs.	GPS	Monitored GPS-collared elk every 2 hours, created a random walk framework model	Elk were more common in areas ≤ 0.5 km of road/ km^2. With ↑ road densities, elk use areas near roads more. Elk avoid >1.08 km of road/ km^2. In areas with no hunting pressure, elk used higher densities of roads.	na	Road placement away from large patches with high quality forage would help to keep elk on the landscape.
Hebblewhite et al. 2005: *1997-1999*	yes	n = 45	Banff, AB and Banff National Park; 6641 km^2	resid.	Obs. Compar.	VHF	Monitored VHF-collared elk 1x/week, monitored mortality in 2 treatments, high wolf and low wolf. Pellet counts to monitor use.	Elk density was significantly ↑ around Banff, where predation was low. Survival ↑ in Banff. Recruitment ↑around Banff. Elk pellet density 3.2 x ↑ in the central no-wolf area.	na	Recolonization of wolves had substantial direct effects on elk demography in BNP, ↓ elk density, survival, and recruitment. Predator exclusion as a result of ⍰ human activity ↓ predation rates by wolves by 60%. Management must account for trophic cascades of predators.
Hurley & Sargent 1991: *1984-1990*	no	n = 88 VHF,	Bob Marshall Wilderness, MT; 1300 km^2	roads	Obs.	VHF	Monitored VHF-collared elk and survival of 43 male elk (1987-1990).	Elk used dense cover during hunting, no change in non-hunted areas. Move away from roads with ↑ hunting pressure. 94% of male mortality = hunting.	na	43% of hunting occurs in areas with roads. Dense cover important during hunting season for security.

Table 6 Cont.

Author: *Study Duration*	**Peer Review**	**Sample Size**	**Location; Study area size**	**Development Type**	**Study Design**	**Collar Type**	**General Methods**	**General Results**	**Housing Buffer**	**Conclusions & Management Recommendations**
Kloppers et al. 2005: *2001-2002*	yes	n = 24	Banff, AB; 4.66 km^2	resid.	Obs., Exper.	VHF	Monitored VHF-collared elk before/during/after treatment. Measured flight distance, vigilance and proximity to town. Treatments human, human and dog and control.	Human and human+dog increased flight distance, human increased distance from town, vigilance decreased in all groups. All effects were tempered by abundance of wolves (the more wolves, the shorter flight distance and distance to town).	na	Predator-resembling aversive conditioning works with humans and humans and dogs. More effort needed in areas with wolves. Dogs more expensive, but quieter. Humans loud w/ firecrackers, but a quieter human chase may also work.
Millspaugh et al. 2001: *1995-1997*	yes	n = 30 elk, n = 558 fecal samples	Custer State Park, SD; 291.5 km^2	roads	Obs.		Quantified fecal glucocorticoid concentrations among free-ranging elk in relation to human activities.	Fecal glucocorticoid measures were least in winter and greatest in summer.	na	Vehicle use on roads also induced a physiological stress response in elk but was highest during the summer.
Morrison et al. 1995: *1985-1992*	yes	na	near Vail, CO; na	resort	Obs., Compar.		Observations two areas before and after ski area expansion, Vail- physical development, Beaver Creek - ↑ human use.	Elk use ↓ significantly in Vail after expansion, especially in China bowl which had more human use and a chairlift. In Beaver Creek overall no effect from development.	na	Hunted elk are affected by ski area expansion, but # of elk ↑ linearly each year after development, especially in open areas with physical development. Habitat variables and amount of human activity important.
Phillips & Alldredge 2000: *1995-1997*	yes	n = 71-85 elk/area /year	Summit County, CO; 500 km^2	recreat.	Obs.	VHF	Monitored VHF-collared female elk 2x/week before and during treatment years. Elk disturbed by hikers in spring, tracked calf success.	Calf:cow ratios ↓incrementally in treatment area each year, 0.225 calves/cow lower in treatment area. Modeling indicates >10 disturbances/cow = population ↓	na	Human disturbance during spring and summer can seriously impact calf success. More studies on actual recreation should be done, restrictions on calving areas should continue.
Picton 1980: *1971-1975*	yes	na	Big Sky, MT; na	resort	Obs.		Pellet transects on mile^2 sections; compared as development increased.	Elk present in most areas, generally avoided roads and human activity, but used resort area.	na	Elk affected by development, resort development not following original plan.
Preisler et al. 2006: *2002*	yes	n = 12	Starkey, OR; 14.53 km^2	recreat.	Exper., Compar.	VHF	Monitored VHF-collared elk 1x/30 min, monitored movements before and after ATV use.	Elk responded to ATVs up to 1000 m, probability of flight higher when elk were closer to the ATV routes.	na	Elk perceive roads or trails as predictable sources of human disturbance. Over successive days of treatment, elk appear to adjust their distributions so that they are located in areas not visible from roads.
Rumble et al. 2005: *2000-2001*	yes	n = 8	Black Hills, SD; 1133 km^2	roads	Obs.	GPS	Monitored GPS-collared elk every 2 hours, analyzed habitat preference in response to roads and human-use.	Elk ↑ movement during the 3 hunting seasons (elk-archery, elk-rifle, deer-rifle) corresponding with ↑ human activity. During the middle of the hunting seasons ≠ move more. Avoided grasslands during daytime hours during the hunting seasons.	na	Movement rates may ↑ energetic demands. Need areas of reduced disturbance (road closures) for elk.

Table 6 Cont.

Author: *Study Duration*	**Peer Review**	**Sample Size**	**Location; Study area size**	**Development Type**	**Study Design**	**Collar Type**	**General Methods**	**General Results**	**Housing Buffer**	**Conclusions & Management Recommendations**
Sawyer et al. 2007: *1999-2004*	yes	n = 55 VHF, 33 GPS	Southwest WY; 2517 km^2	roads	Obs.	GPS, VHF	monitored VHF-collared elk 1x/month 1999-2002 and GPS-collared elk every 4 hours 2003-2004, habitat model for summer and winter habitat.	Elk used higher elevations in summer, close to shrub cover and away from roads. Shifted to areas with lower elevations and southerly aspects in winter.	na	Elk respond to roads especially in summer during high-use. In non-forested areas, managers should recognize the importance of diverse vegetation and not rely on forage to cover ratios.
Shively et al. 2005: *1998-1999*	yes	n = 170	Summit County, CO; 500 km^2	recreat.	Obs.	VHF	Monitored VHF-collared females, monitored calf success, compared to results from Phillips & Alldredge.	Elk reproductive success rebounded after recreation pressure was lifted, back to pretreatment levels, no overcompensation.	na	Elk recovered from recreational disturbance but there may be a threshold beyond which they can't recover. Selective closures needed to prevent disturbance in certain important calving areas.
Wait & McNally 2004: *1996-1998*	no	n= 30	La Plata County, CO; 660 km^2	resid.	Obs.	VHF	monitored VHF collared deer 1x/month and measured selection of use vs availability with a chi2 test	Elk show significant preference towards grass/forb rangelands, sagebrush, and pinyon-juniper habitats, and avoid ponderosa pine and mixed conifer habitats. Elk avoid parcels < 4 ha, and prefer parcels > 24 ha.	na	Elk impacted by development, habituation may be occurring. Need > 24 ha area for hiding cover. Elk avoided agricultural areas. Should cluster homes in larger parcel, maintain open spaces while reducing per-unit cost.
Wisdom et al. 2004: *2002-2004*	no	n = 12	Starkey, OR; na	recreat.	Exper., Compar.	VHF	Monitored VHF-collared deer and elk every 10 minutes during treatments of off-road ATV, horseback riding, mountain biking and hiking	Movement rates were higher in morning and highest for > ATV > mountain bike > hiking > horseback riding. Elk had a high probability of flight response at <1500m from ATV and bikers, <750m from horseback riders and <500 from hikers.	na	Elk demonstrated higher levels of movement during all treatments than during no-treatment. Elk respond to off-road recreation with increased energy expenditure. Limit off road recreation.

Notes: Abbreviations are Exper., experimental; Obs., observational; Compar., comparative; resid., residential; recreate., recreation; Chpt., chapter.

American Pronghorn


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Key Characteristics of Winter Range

Historically 40 – 100 million American pronghorn inhabited summer and winter ranges in the western half of the United States. After a sharp decline in the early 1900s followed by a recovery due to hunting bans mid-century, population estimates today total between 400,000 and 800,000 (Yoakum 2004a). Pronghorn are an obligate grassland species and the historic cultivation of land for agriculture as well as other human disturbance has reduced their range by as much as 64% (Laliberte and Ripple 2004). Snow depth has been found to be the most important factor influencing pronghorn winter range selection (Bruns 1977, Berger et al. 2006). Pronghorn will move to avoid the greatest snow depths, making travel corridors within winter range very important (Yoakum 2004c). Generally, low snow depths < 30 cm are selected while snow > 45 cm can restrict mobility (Yoakum 2004c, Berger et al. 2006, Berger et al. 2007). Some studies have reported pronghorn use of topographic relief, as well as shrubs and trees to avoid high winds (Bruns 1977, Wood 1989, Yoakum 2004c). However, slopes greater than 20%, rock cliffs, steep terrain, and dense woody vegetation are generally avoided (Yoakum 2004c, Autenrieth et al. 2006).

Because pronghorn occupy three different biomes – prairie, shrub-steppe and desert – winter forage is varied (Yoakum 2004d). Annually, pronghorn prefer forbs over shrubs and grasses (Mitchell and Smoliak 1971, Autenrieth et al. 2006). In winter, pronghorn occupy open habitat dominated by sagebrush (Berger et al. 2007) or bunchgrass prairie (Wood 1989). When snow accumulates, shrubby browse is generally the most important vegetation available to pronghorn (Mitchell and Smoliak 1971, Yoakum 2004d). In a low sagebrush area, pronghorn selected for greasewood and rabbitbrush (Boccadori 2002). Pronghorn prefer varied native vegetation over a single vegetation type (Yoakum 2004d). Due to the small relative size of their rumen compared to other ungulates, pronghorn are very selective regarding the parts of shrubs on which they browse and are considered 'dainty' eaters (O'Gara 2004c). Pronghorn will browse on agricultural fields and have caused considerable damage to winter wheat crops and alfalfa in some areas (Yoakum 2004b, Autenrieth et al. 2006, Jones et al. 2008a).

In winter pronghorn congregate in herds of approximately 30 – 100 individuals (though herds up to 1000 individuals have been reported, Bruns 1997) with a large amount of mixing between groups (Sawyer and Lindzey 2000). In response to severe weather and snowfall they will travel in single-file lines, develop hierarchies at cratering sites and lie down in groups (Bruns 1969). Pronghorn generally exhibit high fidelity to winter range (Sawyer and Lindzey 2000, Sheldon 2005, Berger et al. 2007), but may also occupy multiple ranges between years in response to weather severity (Amstrup 1978). The size of seasonal home ranges likely depends on local habitat quality and various studies have found contradictory results with winter home ranges being larger than summer ranges in some regions (Hoskinson and Tester 1980, Sheldon 2005) and smaller in others (Boccadori 2002, Jones et al. 2007).

Response to Development


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Similar to other ungulates, pronghorn exhibit brief overt reactions in response to human disturbance. The adaptation by pronghorn to arid open-habitats may predispose them to rapid flight from perceived danger. In Antelope Island State Park, Utah, pronghorn exhibited a 70% probability of flushing from recreationists within 100 m from trails. Pronghorn tended to flush more often and flee further than bison or mule deer (Taylor and Knight 2003). Pronghorn also displayed increased vigilance in response to high levels of vehicular traffic associated with resource extraction (Berger et al. 1983). However, other studies have determined that military activities including overflights, sonic booms and ground activities had little impact on the behavior or habitat use of endangered Sonoran pronghorn (*A. a. sonoriensis*) in Arizona (Krausman et al. 2004, Krausman et al. 2005). Pronghorn exposed to military activity traveled more, stood alert more and foraged less than the closest population (different subspecies) without military activity. However, differences were more likely due to the distribution of resources than reactions to human activity. Further, Sonoran pronghorn tended to use areas closer to disturbed sites, presumably as a result of increased forage production, visibility and ease of movement (Krausman et al. 2005).

Most studies regarding pronghorn response to development concern the changes in habitat selection, migration routes and population-level impacts of the effects of oil and gas extraction (see Hebblewhite 2008). No studies specifically examined the impact of residential development on pronghorn, though houses have been implicated as a major factor in blocking migration corridors (Sawyer et al. 2005). However, other research on linear features such as fences and roads (structures inherently associated with residential areas) demonstrate the negative effects of development on pronghorn. Roads are a major concern to pronghorn and can create barriers to movement (Yoakum 2004b) as well as direct mortality consequences through vehicle collisions (O'Gara 2004b, Gavin and Komers 2006). Recent studies demonstrate that pronghorn exhibit increased levels of vigilance near roads, especially when young are present and group size is small (Gavin and Komers 2006). Other studies, however, have shown that pronghorn will use plowed roads as movement corridors (Bruns 1977). Unfortunately, this tendency to use snow free areas has lead to the death of 800 pronghorn on railroad tracks in Montana during the winter of 2010-2011 where especially deep snows hindered pronghorn movements (Whittle 2011). Pronghorn have been known to use roads to avoid the fences and gain access to the Bridger-Teton National Forest in Wyoming (Sawyer and Lindzey 2000), suggesting that habitat fragmentation is a result of right-of-way fences rather than roads.

The negative effects of fences on pronghorn populations have been well-documented. Unlike deer and elk, pronghorn rarely jump fences and require approximately 40 cm of space below to lowest wire in a fence to crawl underneath (Yoakum 2004b). Few fences are built to facilitate pronghorn movements, and consequently, fencing is a major source of habitat fragmentation (Sawyer and Rudd 2005, Paige 2008). Snow accumulation in winter can decrease the available crawling space and severely impede movement (Autenrieth et al. 2006). Other studies have found foraging rates declined in the proximity to fences, suggesting that pronghorns may perceive security differently near fences (Berger et al. 2007, Beckmann and Seidler 2009). Further, in southwestern Wyoming, pronghorn selected seasonal home ranges in areas with the lowest density of fences (Sheldon 2005).

Several studies have documented the response of pronghorn to the development of the Jonah and Pinedale Anticline natural gas formations in the Upper Green River basin in southwest Wyoming (Sawyer and Lindzey 2000, Berger et al. 2006, Berger et al. 2007, Beckmann et al. 2008, Beckmann and Seidler 2009). In a five year study to determine the impacts of progressive oil and gas development on wintering pronghorn, Joel Berger and colleagues monitored collared individuals in both control and experimental areas based on *a priori* proximity to energy development. Preliminary findings did not detect a significant response to development in survival rates, body mass, stress levels and progesterone levels. However, even in year one, results indicated that pronghorn generally avoided habitat fragments less than 600 acres and the most heavily developed areas (Berger et al. 2006). In the second year of the study, strong avoidance of development was detected for certain individuals, though vital rates remained similar between control and experimental areas (Berger et al. 2007). By the third year of the study, Beckmann et al. (2008) began to detect population-level avoidance of gas fields with the highest activity levels. Further data revealed that pronghorn reduced use of developed areas in previously highly-used area as compared to more intact parcels. While these behavioral responses suggest some impact from increased development, the preliminary results do not indicate a decline in survival for pronghorn wintering in gas field areas compared to those utilizing areas away from human activity (Beckmann and Seidler 2009).

Another large-scale study in southern Alberta also examined the response of pronghorn to anthropogenic disturbance. Preliminary results indicate pronghorn tend to select native prairie cover and avoid agricultural land, pipelines, gravel roads, and active well sites at the stand level (Jones and Grue 2006, Sheriff 2006, Jones et al. 2008b). The distribution of monitored individuals within a large military training base in Alberta was negatively related to well pad density in the summer, but not in the winter (Seagel 2007). Similarly in the Rattlesnake Hills of Wyoming, Easterly et al. (1991) found that pronghorn densities were substantially lower closer to energy development and radio-collared pronghorn avoided well sites during disturbance.

However, this study lacked predevelopment distribution data, making inferences about the effects of energy development less robust than the Pinedale study (Hebblewhite 2011).

Habituation

The thresholds that determine habituation in pronghorn have not been well studied though it is generally recognized that pronghorn can habituate to chronic human activity (Krausman et al. 2004, Krausman et al. 2005). Some pronghorn will freely use areas near development while others will not (Berger et al 2007). However, their main response to any disturbance is flight and they generally run longer and sooner than other ungulates (Taylor and Knight 2003). Even when raised in captivity, pronghorn tend to be flighty and react strongly to new disturbances (Grandin 2007).

Migration

Pronghorn undergo one of the greatest long-distance over-land migrations of the world travelling up to 550 km annually from winter to summer range and back (Berger 2004). Extreme migrations of 445 km one-way have even been recorded (Jones et al. 2007). Most (approximately 70 – 100%) pronghorn migrate although some plasticity exists (White et al. 2007). Pronghorn exhibit high fidelity to migration routes. In fact, in Wyoming, archaeological data confirms that one migration corridor has been in use for at least 6000 years (Sawyer et al. 2005, Berger et al. 2006). The timing of migration is flexible, as pronghorn often follow the snowline back to higher elevation summer ranges in spring (Sawyer et al. 2005). Fall migration is thought to be induced by the amount of moisture in vegetation or temperature rather than snowfall (Hoskinson and Tester 1980, Sheldon 2005). Pronghorn also use staging areas where they gather before further pursuing migration (Sawyer and Lindzey 2000).

Unfortunately, approximately 78% of migratory behavior by pronghorn has been lost in the Greater Yellowstone Ecosystem (Berger 2004).The main problems regarding development and pronghorn migration are corridor bottlenecks or “pinch points” and fences. Bottlenecks are topographic features through which pronghorn are funneled during their migration. Because of the small size and high use of these areas, minimal development can have a disproportionate affect on a pronghorn population. One well-studied example of this is the Trappers Point bottleneck in Wyoming. Pronghorn use this route during migration from the Green River basin to the Jackson Hole region. Historically, the bottleneck measured approximately 1.6 km across. Today, due to roads and residential development, the bottleneck is half that length. Almost all of the pronghorn and half the mule deer (1000 pronghorn and up to 3500 mule deer) in the Sawyer et al. (2005) study, travel through the Trappers Point bottleneck to reach summer range in Jackson Hole. Any increase in development has the potential to significantly affect pronghorn migration (Berger 2004, Sawyer et al. 2005, Berger et al. 2006, White et al. 2007). Fences crossing migration pathways can cause similar problems. As addressed in the development section, pronghorn have difficulty crossing fence lines. Fencing of private lands can directly impede migration or create new migration bottlenecks (Yoakum 2004b). Since bottlenecks occur in many migration routes, it is important to identify where they occur and conserve the land around them to ensure the integrity of pronghorn migration (White et al. 2007).

Disease

Pronghorn are generally less susceptible to disease than other ungulates, likely because they live on arid range. Bluetongue virus is often considered the most serious disease for pronghorn. It causes mass die-offs due to malnutrition and hemorrhage. Cattle can pass the disease to pronghorn as they are carriers, but do not develop symptoms (O'Gara 2004a). Pronghorn can also contract parasites from livestock (O'Gara 2004b). They are susceptible to severe weather and environmental stochasticity which can cause mass winter mortality and reduce genetic variation in small isolated populations (Dunn and Byers 2008).

Predation

Adult pronghorn generally have high survival rates, but fawns are vulnerable to predation. Research has suggested that fawn survival is positively correlated with wolf density and birth weight. This is likely because the presence of wolves lowers the density of transient coyotes (significant predators of pronghorn fawns), although resident coyote densities were similar with or without wolves (Berger et al. 2008). Since large predators tend to avoid development more than mesopredators, pronghorn fawn survival could be negatively impacted by increased development that facilitates coyote predation through indirect trophic interactions.

Summary

Pronghorn are highly adapted to native grass prairie habitats of the West (Sheriff 2006). Unfortunately, the historic conversion of grasslands to agriculture have severely reduced available habitat (Seagel 2007). Further, diverse native forbs selected by pronghorn are often greatly reduced near development (Wood 1989, Hansen et al 2005). Because pronghorn need large contiguous areas with relatively few physical barriers to complete large seasonal migrations, the increase in leasing of public lands for energy development, transportation infrastructure, fencing and rural residential development are all future threats to pronghorn persistence. Various environmental variables such as snow accumulation, habitat quality, barriers to movement and predation all influence the minimum patch size of functional winter range. There is a growing need to protect important winter range and migration corridors. Fencing is likely one of the greatest threats to pronghorn movement, and will occur more frequently with increased residential development. Modifying the bottom wire of fences to allow pronghorn to crawl underneath is one management solution (Paige 2008). Other options to facilitate movements include opened gates (Bruns 1977) or highway underpasses (Sawyer and Rudd 2005). Mitigating the effects of residential development that occurs in critical migration bottlenecks should receive the high conservation priority.

No studies have specifically examined the impact of residential development on pronghorn behavior or demography. However, research on the impacts of human disturbance on pronghorn indicates that pronghorn increase vigilance, flight and behavioral avoidance which can increase energy expenditure and decrease the ability of pronghorn to respond to other environmental stressors. Recent large scale projects in Wyoming and Alberta have the potential to shed light on the population-level consequences of human development on pronghorn. Results of these studies will help facilitate our understanding of how future exurban development will influence pronghorn populations.

The ability of pronghorn to habituate to certain levels of disturbance, especially when not hunted or harassed, makes defining a threshold between ‘wild’ and ‘non-wild’ winter range difficult. During severe winters pronghorn may use agricultural lands to maintain positive energy budgets and the high quality forage in these areas has the potential to eliminate migratory behavior (Jones et al. 2008a). Resident habituated pronghorn can deplete agricultural crops and may be at higher risk of vehicle collisions. High pronghorn population densities have been shown to decrease population growth and fawn survival (Sheriff 2006). In general, pronghorn persistence is dependent on large-scale, multi-jurisdictional initiatives to protect critical migration corridors and winter ranges.


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Table 7. Review of scientific literature on the effects of human disturbance on American pronghorn, summarizing study authors, study duration, whether the study was peer reviewed or not, sample size, location, study area size, development type, study design, collar type, general methods and results, minimum patch size requirements and conclusions and management recommendations.

Author: *Study Duration*	**Peer Review**	**Sample Size**	**Location, Study area size**	**Development Type**	**Study Design**	**Collar Type**	**General Methods**	**General Results**	**Min patch size**	**Conclusions & Management Recommendations**
Berger et al. 2006, 2007, Beckmann et al. 2008, Beckmann & Seidler 2009: *2005-2008*	no	n = 150/yr	Upper Green River Basin, WY; 4000 km^2	resource extraction	Obs., Compar.	GPS	Multi-year study. Monitored GPS-collared pronghorn every 3 hours, monitored survival rates, body mass, stress levels, and progesterone levels.	Pronghorn avoid fragments < 600 acres, individuals avoided densest development. Vital rates remained similar between control and experimental areas. Some population-level avoidance of gas fields with the highest activity levels.	2.428 km^2	Pronghorn reduced use of developed areas in previously highly-used area as compared to more intact parcels. Majority of locations (>94%) in winter 07-08 were in the lowest disturbance level quartile. No corresponding impact on pronghorn demography. Survival rates of pronghorn wintering in gas field areas were similar to those utilizing areas away from human activity.
Gavin & Komers 2006: *na*	yes	n = 112 observations 16 hrs	Southeast AB; na	roads	Obs.		Observed pronghorn response to roads with different numbers of vehicles.	Pronghorns < 300 m from roads ↑ vigilance and ↓ feeding. Vigilance ↑ when fawns present. Larger groups ↓ vigilance.	na	Pronghorn are more risk-adverse near roads. Road traffic level and placement should be considered by managers.
Jones & Grue 2006, Jones et al. 2007, 2008: *2005-2006*	no	n = 25/yr	Southern AB; 63,000 km^2	resource extraction	Obs.	GPS	Monitored GPS-collared pronghorn every 4 hours. Modeled habitat selection.	% of native prairie in winter ranges was significantly greater than the available winter ranges. Locations were further from collector roads and well sites than available points in 2006.	na	Preliminary results suggesting that pronghorn selection patterns may be influenced by energy development.
Krausman et al. 2004, 2005: *1999-2002*	yes	n > 265 days of observations	Barry M. Goldwater Range; 5,739 km^2, Buenos Aires NWR, AZ; 455 km^2	military activities	Obs.		Observed Sonoran pronghorn behaviors and locations with spotting scopes on military base and in non-disturbed National Wildlife Refuge.	Pronghorn exposed to military activity foraged less and stood and traveled more than pronghorn not exposed to military activity. Other behaviors were similar between two populations. 2nd study: 73% of locations occurred in proximity to disturbed sites and roads.	na	The military activity had only marginal influence on Sonoran pronghorn. Pronghorn behavior exposed to military activity was similar to behaviors of pronghorn not exposed. Disturbed landscapes may attract Sonoran pronghorn by creating favorable forage.
Sawyer et al. 2005: *1998-2001*	yes	n = 34	Western WY; 15000 km^2	resource extraction, resid.	Obs.	VHF	Monitored VHF-collared pronghorn along migration routes ever 7-10 days during migration.	Pronghorn migrated 116-258 km. A number of significant bottlenecks were observed. Housing developments narrowed width of the bottleneck to < 800 m. All 1,500–2,000 pronghorn moved through the bottleneck twice a year.	na	Fences, road networks, and increased human disturbance associated with energy and housing developments influence the effectiveness of pronghorn migration routes. Special attention should be paid to migration routes especially where bottlenecks occur.

Table 7 Cont.

Author: *Study Duration*	**Peer Review**	**Sample Size**	**Location, Study area size**	**Development Type**	**Study Design**	**Collar Type**	**General Methods**	**General Results**	**Min patch size**	**Conclusions & Management Recommendations**
Seagel 2007: *2003-2005*	no	n = 49	Canadian Forces Base Suffield, AB; 2690 km^2	resource extraction, roads	Obs.	GPS	Monitored GPS-collared pronghorn and flew aerial surveys. Modeled habitat selection.	Pronghorn avoided burned areas in winter. Distribution was negatively related to well density in summer, but not in winter. Weak negative response by pronghorn to major roads in summer and winter.	na	Pronghorn responded to biophysical and anthropogenic features on the landscape differently in the summer and winter. Need more data on military activities and oil and gas development to make stronger conclusions.
Sheldon 2005: *2002-2003*	no	n=72	Southwestern, WY; 2,800 km^2	fences	obs.	GPS	Monitored GPS-collared pronghorn 1-3x/day. Modeled HR.	Fence density was lower in HRs than in the study area. Fence density was greater within the periphery of HR. Most pronghorn (64%, n=28) were migratory and routes encountered fewer fences than random travel.	na	Pronghorn choose areas with lowest fence densities. Fences influenced distribution and movement patterns. Known movement corridors must be maintained. Obstacles to pronghorn movement, including fences, roads, and development should be limited.
Taylor & Knight 2003: *2000-2001*	yes	n = 88 observations	Antelope Island, UT; 104 km^2	recreat.	Obs., Survey		Observed pronghorn response to humans, surveyed recreationists.	Pronghorn exhibited 70% probability of flushing from on-trail recreationists < 100 m from trails. Flight occurred when 230 m from trail and distance moved was 150 m.	na	Animals were between 50 m and 200 m from trails. Need to ↑ public education, limit off-trail use and trail use during calving/fawning. Enforce buffer zones around wildlife.

Notes: Abbreviations are HR, home range; NWR, National Wildlife Refuge; Obs., observational; Compar., comparative; resid., residential.

Bighorn Sheep


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Key Characteristics of Winter Range

Mountain sheep were once distributed continuously throughout the mountains of western North America. Human encroachment, competition with domestic livestock and diseases have all contributed to the current fragmentation of local populations (Armentrout and Boyd 1994, Beecham et al. 2007). Rocky Mountain bighorn sheep (*O. canadensis canadensis*) are distributed from central British Columbia and Alberta to New Mexico (Demarchi et al. 2000). Two subspecies, the endangered Sierra Nevada bighorn (*O. c. sierrae*) and the desert bighorn (*O. c. nelsoni*) occur throughout the desert southwest of the U.S. and in the central Sierra Nevada range. Thinhorn sheep (*O. dalli*) occur primarily in Alaska, the Yukon Territory, western Northwest Territories, and north of 56° latitude in British Columbia (Demarchi and Hartwig 2004). Among thinhorn sheep there are two subspecies classified by coat color: the white Dall's sheep (*O. d. dalli*) and the darker Stone's sheep (*O. d. stonei*) which only occur in the Yukon and northern British Columbia (Worley et al. 2004).

In the Rocky Mountains, bighorn sheep often occupy distinct seasonal ranges though some herds may stay in the same area year-round (Geist 1971). Winter ranges are commonly at lower elevations on south, southwestern or southeastern slopes. These aspects facilitate solar radiation and provide exposed grassy slopes where winds reduce snow cover (Shackleton et al. 1999). Sheep may also move to high-elevation, wind-swept ridges when snow accumulation increases at lower elevations (Geist 1971). Mountain sheep are a highly vigilant species and spend a large portion of time in open habitats in order to watch for potential predators (Hutchins and Geist 1987, Valdez and Krausman 1999). Thus, winter range is often associated with steep escape terrain (usually > 27°) and use of forested habitats is rare (Shackleton et al. 1999, Dicus 2002, DeCesare and Pletscher 2006, Dekker 2009). In fact, bighorn sheep heart rate has been shown to increases with increasing distance from escape terrain (Stemp 1982).

Some researchers describe mountain sheep as opportunistic feeders, sampling any forage available (Shackleton et al. 1999), while others suggest that bighorns are specialized grazers adapted to a diet of coarse graminoids (Geist 1971). Differences in diet descriptions are likely a result of the vastly different habitats, elevations and aridity occupied by different subspecies. Bighorn sheep are known to forage on shrubs, forbs and grasses in the winter (Wagner and Peek 2006). Burns can play an important role in the quality of winter range and can increase crude protein, visibility, timing of spring green-up and may increase overall habitat carrying capacity (Holl et al. 2004, Greene 2010). Bighorn populations often segregate into age and sex groups to reduce competition during much of the year. Females are known to display high fidelity to seasonal home ranges, while males are more likely to disperse (DeCesare and Pletscher 2006). Because no studies have examined the impacts of residential development on Rocky Mountain bighorn sheep, I will review effects of all types of human disturbance on all subspecies of wild mountain sheep in North America.

Response to Development

Similar to other ungulates, approach by humans on foot tends to illicit a greater response in mountain sheep than that of vehicular stimuli. In Utah, bighorn sheep fled three times more often in response to hikers than to vehicles (Papouchis et al. 2001). Even when sheep do not demonstrate overt behavioral reactions, they may still be under physiological stress. MacArthur et al. (1982) found that in southwestern Alberta, cardiac and behavioral responses of bighorn sheep were greatest when humans approach with a dog or approached from over a ridge. Loehr et al. (2005) studied the response of Dall's sheep to human presence in the Yukon Territory. They found that female sheep were more sensitive than males and decreased bedding and increased foraging when humans were present, whereas rams had no behavioral changes. Similarly, in Joshua Tree National Park, California, female sheep moved more often, used steeper slopes and areas farther from trails during high levels of human activity resulting in temporarily displacement from habitat (Thompson et al. 2007). Further, winter recreation has been shown alter bighorn sheep behavior possibly leading to increased energy expenditure, reduced reproduction, starvation, and lower resistance to disease and predation (see reviews by Legg 1998, Canfield et al. 1999, Olliff et al. 1999).

Human disturbance due to aircraft overflights is especially detrimental to wild sheep which are often found on exposed mountain slopes where cover is scarce. In California, Bleich et al. (1990, 1994) monitored the distribution and movements of bighorn sheep following disturbance by helicopter surveys. Their results indicated adult sheep moved 2.5 times farther during surveys and in the days following surveys than on non-survey days. The authors suggest that increased movement may lead to altered foraging rates, increased susceptibility to predators and increased stress. Bighorn sheep in western Arizona also demonstrated increased movements 19% of the time when exposed to low-level overflights from fixed wing aircraft. When aircraft approached within 50 m of the ground sheep left the area (Krausman and Hervert 1983). In Grand Canyon National Park, Stockwell et al. (1991) found that desert bighorns responded to helicopter disturbance within 250-450 m during the winter. Disturbance resulted in a 43% reduction in foraging efficiency.

Direct mortality due to vehicle collisions probably does not have large demographic consequences, but there are incidental reports of groups of bighorn sheep hit on roads across the West and into Canada along the Alaska highway (Gunther et al. 1998, British Columbia Ministry of Environment 2000). For example, eight bighorn sheep, including two trophy rams, were killed on Highway 1, west of Anaconda, Montana, in 2010 (Plaven 2010). This problem may be especially apparent where residual salt remains on roads due to the importance of mineral licks to bighorn sheep health (Tankersley 1984).

The indirect effects of roads likely have greater demographic consequences as a result of avoidance and displacement from key habitats. Roads can act as barriers to movement and may fragment habitat between important seasonal sites such as mineral licks. In Colorado, Keller and Bender (2007) observed attempts of bighorn sheep to cross a road to access an essential mineral site. They found that when traffic was high and people were present at the site, bighorn sheep made more attempts and took longer to cross the road. Furthermore, the number of bighorn sheep utilizing the mineral lick declined from nearly 800 sheep in 1996 to only 243 during the summer of 2003. In Denali National Park, unsuccessful road crossings by Dall's sheep have also been observed (Dalle-Molle and Van Horn 1991). Papouchis et al. (2001) studied desert bighorns response to roads and vehicles in Canyonlands National Park, Utah. They found that bighorns fled from vehicles in 17% of encounters. Heavy traffic caused greater avoidance and sheep fled most often when within 200 m of the road and did not respond if they were more than 800m from the road. In general, most bighorn sheep avoided roads and were on average 39% farther from roads than other areas. This avoidance produced a 20-36% decrease in the use of suitable habitat along the road corridor within the study area.

Human development may also influence bighorn sheep population dynamics and persistence. On the Rocky Mountain Front in Montana, seismic lines caused a significant decline in home range size of bighorn sheep. In the year following four large-scale cutlines, bighorns were excluded from 28% of their traditional fall range (Hook 1986). The 1988 Winter Olympics in Calgary, Alberta, caused local bighorn sheep populations to abandon parts of their range adjacent to the downhill skiing venue on Mt. Allan. After the ski area was opened in 1986, Jorgenson (1988) observed an 18% decline in the population due to decreased lamb survival and hunting pressure. A study by Epps et al. (2005) indicated that roads and anthropogenic features such as canals and fences have reduced genetic diversity for desert bighorn sheep populations in the Mojave and Sonoran deserts of California. Forest encroachment as a result of fire suppression may also block migration corridors and lower dispersal movements (Beecham et al. 2007), and may result in range abandonment (Etchberger et al. 1989). Because many sheep populations are inherently small (< 50 individuals) a significant decrease in genetic diversity due to barriers to movement may cause habitat fragmentation, impact metapopulation stability and have large implications on extinction risk (Berger 1990, Armentrout and Boyd 1994).

The effects of human infrastructure and mining development on mountain sheep behavior, abundance and habitat selection have been studied in the Mojave Desert of California, where a heap-leach gold mine was placed near a critically important spring used by bighorn sheep in the summer. Oehler et al. (2005) measured the influence of mining activity on habitat selection, home-range dynamics and foraging ecology of two subpopulations of bighorn sheep; one that occupied an area within the vicinity of the mine, and a control population in a non-mined area. They recorded few changes in sheep activity that could be directly correlated with mining. Their results did suggest that female sheep near the mine spent more time vigilant during the summer and fall and consequently spent less time foraging. Oehler et al. (2005) proposes that even a small decrease in forage intake could affect survival in populations of desert bighorns that must persist in marginal environments. Bighorn sheep within the perimeter of an active copper mine associated with vehicles and blasting in Arizona foraged up to 6% less than sheep in non-mined areas but did not appear to be more vigilant (Jansen et al. 2006,2007). The authors conclude that bighorn sheep may be able to habituate to predictable disturbance when subjected to years of mining activity.

Habituation

There is evidence that in certain conditions bighorn sheep may habituate to temporally and spatially predictable human activity such as low levels of recreation or mining activity (Horesji 1976, Wehausen et al. 1977, Jansen et al. 2007). Habituation to jet overflights has been observed in two studies that monitored bighorn sheep heart rate and behavior before, during and after being disturbed by loud noise associated with F-16 fighters. Krausman et al. (1998) found that in Nevada, the heart rate of bighorn sheep in a large enclosure flown over by jets only increased in 21 of 149 overflights and returned to preflight levels within 120 seconds. In a lab setting, Weisenberger et al. (1996) observed that bighorn sheep and mule deer were able to habituate rapidly to noise from a simulated jet overflight. They recorded 34 incidents of increased heart rate in bighorns during 112 overflights and heart rate returned to normal within 60-180 seconds. These results suggest that bighorn sheep do not view overflights by jet aircraft as a threat. The level of bighorn sheep habituation to human activity likely varies between regions and the impact of development should be examined on a case-by-case basis (Beecham et al. 2007).

Migration

Mountain sheep are known to migrate between seasonal ranges. Typical migrations can range between 5 – 51 km (Hengel et al. 1992, Shackleton et al. 1999) but can also include shorter elevational migrations (Beecham et al. 2007). Sheep likely learn traditional migration routes from their mothers and fidelity to theses established corridors is relatively high (Geist 1971). As discussed earlier, changes in forest composition as a result of fire suppression and anthropogenic barriers such as canals, roads and fences may fragment populations of bighorn sheep (Epps et al.

2005, Beecham et al. 2007). Thus, maintaining routes between mountain ranges is important to prevent genetic isolation and extinction risk.

Disease

Disease plays a significant role in bighorn sheep natural history. With the arrival of European settlers to the West in the early 1900s came dramatic declines in bighorn sheep populations. These declines were likely the result of transmission of diseases and parasites from domestic livestock, particularly domestic goats and sheep (Beecham et al. 2007). Many different diseases affect bighorn sheep including: psoroptic scabies, sheep nasal botfly, chronic sinusitis, gastrointestinal parasites, bluetongue, paratuberculosis, verminous pneumonia, contagious ecthyma, mandibular osteomyelitis and lungworms (Bunch et al. 1999, George et al. 2009). However, bacterial pneumonia (caused by bacteria in the *Pasteurellaceae* family) is likely responsible for most of the declines and large-scale (> 50% of individuals) die-offs of bighorn sheep. Generally a combination of stress related factors such as harassment by humans, poor nutrition, severe weather or high density dependence trigger die-offs (Bunch et al. 1999). Low lamb recruitment can persist for years following a die-off and in some situations survivors can continue to infect other herds leading to even larger population-level consequences (George et al. 2009). Overgrazing and competition with domestic animals can also contribute to further declines. These epidemics can be exacerbated by other diseases, parasites or environmental stress such as human disturbance and increased residential development near bighorn sheep winter range could increase bighorn sheep susceptibility to disease (Beecham et al. 2007).

Predation

The large historic declines in bighorn sheep populations have likely altered predator-prey dynamics across their range (Beecham et al. 2007). While predators can influence bighorn sheep populations in some situations, predation likely has less of an impact on population dynamics than disease or habitat fragmentation. Bighorn sheep have adopted a successful anti-predator strategy by using open areas near escape terrain which allows them to detect and flee from cursorial predators such as wolves (Geist 1971, Dekker 2009). However, in some situations ambush predators, like mountain lions, have negatively impacted sheep populations (Hayes et al.

2000, Beecham et al. 2007, Greene 2010). Some researchers have speculated that mountain lion predation on bighorn sheep increased following a decline in mule deer numbers in California (Holl et al. 2004). Alternately, research by Rominger et al. (2004) indicates that mountain lion populations in central New Mexico were subsidized by cattle and thus maintained higher population numbers and had a significant negative impact on bighorn sheep populations.

Summary

Unfortunately, no specific research has been conducted on the effects of residential development on bighorn sheep behavior or demography, likely because of the general lack of overlap between current bighorn habitat and residential development. Historic reports suggest that bighorn sheep once ranged far from rugged mountain terrain now considered preferred habitat (Cowan 1940, Valdez and Krausman 1999). The overwhelming expansion of urban development, resource extraction, disease, competition with domestic livestock and habitat fragmentation have reduced historic ranges by 40% (Laliberte and Ripple 2004). The large-scale declines and extirpations of bighorn sheep populations near western cities like Tucson are likely a result of human encroachment, though no cause and effect studies documented the declines (Krausman et al. 2001). Further, successful translocation projects across the West have made identifying the underlying impacts of residential development difficult.

Mountain sheep are highly vigilant and exhibit a number of overt behavioral reactions in response to human disturbance. In general, approach by humans on foot elicits a stronger behavioral reaction than vehicle traffic. Where human development intersects sheep range roads may act as a barrier to movement, especially when highways bisect migration routes or corridors to important seasonal mineral lick sites. Other research suggests that mountain sheep avoid roads with high traffic volumes and in some cases may even abandon habitat following disturbance events (Armentrout and Boyd 1994). Aircraft overflights can increase movement rates, heart rates, and interrupt foraging and resting behaviors. Industrial mining can disrupt foraging efficiency by increasing time spent vigilant in the proximity of the mine, though few studies have linked behavioral changes to long term demographic consequences. Disease and parasite levels have also increased following human disturbance. Evidence for habituation temporally and spatially predictable human activity and to jet overflights has been proposed in certain situations. Other human mediated impacts such as an increase in invasive species that decrease native forage (Dekker 2009) and competition with domestic livestock also threaten bighorn sheep populations (Beecham et al. 2007). The situation face by bighorn sheep is eloquently embodied by Kruasman et al. (2001:226), who write, "society is faced with a difficult choice: either restrict suburban expansion and control human activities within sheep habitat or accept the reality that sheep and expanding developments are simply not compatible." Protection and maintenance of mountain sheep habitat is essential to prevent extirpations similar to those observed in the past century.


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Table 8. Review of scientific literature on the effects of human disturbance on mountain sheep, summarizing study authors, study duration, whether the study was peer reviewed or not, species: (***Oc***–*Ovis canadensis*, ***Ocn***–*O. c. nelson*, ***Ocm***–*O. c. mexicana*, ***Odd*** –*O. dalli dalli*), sample size, location, study area size, development type, study design, collar type, general methods and results, and conclusions and management recommendations.

Author: *Study Duration*	**Peer Review**	**Spp.**	**Sample Size**	**Location, Study area size**	**Development Type**	**Study Design**	**Collar Type**	**General Methods**	**General Results**	**Conclusions & Management Recommendations**
Bleich et al. 1990, 1994: *1988-1990*	yes	*Oc*	n =36	San Bernardino County, CA; 225 km^2	helicopter	Obs.	VHF	Monitored VHF-collared sheep 1x/week. Monitored response to low flying helicopters and compared to non-disturbed sheep.	Sheep moved 2.5x further the day following a heli survey than the previous day, some left the study area after surveys. Even low intensity heli surveys had a substantial effect on mountain sheep movement/distribution.	Movement by mountain sheep during helicopter survey may produce biased estimates of population size. Helis and fixed-wing aircraft may reduce foraging efficiency, alter use of habitat, increase susceptibility to predation, increase nutritional stress.
Etchberger et al. 1989: *1987-1988*	yes	*Ocm*	n = 11	Coronado National Forest, AZ; 78 km^2	recreat.	Obs.	VHF	Monitored VHF-collared sheep to find current HR, compared habitat characteristics in abandoned vs used home range.	Habitats used by bighorn sheep have less human disturbance and higher forage biomass.	Human disturbance seems to be key factor in change of habitat. Fire is important and restoration fire could enhance sheep habitat. Reducing human activity in abandoned areas could enhance restoration.
Hook 1986: *1982-1984*	no	*Oc*	n = 8	Rocky Mountain Front, MT; na	resource extraction	Obs.	VHF	Monitored VHF-collared sheep approx 2x/week, noted habitat type along with location.	The average annual home range size significantly declined (28%) from average following seismic line disturbance.	sheep were affected by the placement of seismic lines, especially in the fall, which may have population-level effects. Oil and gas activities are detrimental to bighorn range.
Jansen et al. 2006, 2007: *2003-2005*	yes	*Oc*	n = 21, n = 12	Silver Bell Mountains, AZ; 73 km^2, 58 k km^2	resource extraction	Obs.	VHF	Monitored VHF-collared sheep 1x/day and recorded habitat type. Recorded behavior of focal animal in each group.	Sheep used areas within the mine site. Sheep fed less (6%) while inside the mine perimeter. Other behaviors (e.g., bedding, standing, alert, and interacting) were similar inside/outside mine perimeter.	Minor differences in sheep behavior inside and outside the mining area. Sheep appeared to habituate to mining activity. Emphasis placed on restoration, especially in desert or semi-desert environments.
Jorgenson 1988: *1986-1987*	no	*Oc*	na	Alberta, Canada; na	resort	Obs.		Observed sheep from ground and air, measured variables to model population.	18% decline in population, including lower lamb survival, range abandonment, and more lungworm larvae.	First year negative effect of ski resort, but population rebounded in subsequent years. Continue to monitor herd vital rates and use mitigation measures to avoid unnecessary harassment.
Keller & Bender 2007: *2002-2003*	yes	*Oc*	n = 357 obs. in 02 and n = 159 obs. in 03	Rocky Mountain National Park, CO; 1076 km^2	recreat.	Obs.		Observed sheep crossing attempts and number of vehicles.	Number of groups visiting key mineral lick adjacent to a road declined as human disturbance increased. The time and number of attempts required by bighorn to reach Sheep Lakes was positively related to the number of vehicles and people present.	Negative effects of road and human avoidance may affect population dynamics. Recommended seasonal human use restrictions to maintain sheep populations. Also moving the interpretive site, moving the road or constructing an overpass.

Table 8 Cont.

Author: *Study Duration*	**Peer Review**	**Spp.**	**Sample Size**	**Location, Study area size**	**Development Type**	**Study Design**	**Collar Type**	**General Methods**	**General Results**	**Conclusions & Management Recommendations**
Krausman et al. 1998: *1990-1992*	yes	*Ocn*	n=22 in enclosure n=5 HRM	Desert National Wildlife Refuge, NV; 3.2 km^2	Jet aircraft	Exper.	Heart Rate	Monitored sheep behavior and habitats use in enclosure subjected to 149, F-16 overflights. Recorded heart rate and behavior of sheep 15 min pre-overflight, during the overflight, and postoverflight.	Heart rate increased above preflight levels in 21 of 149 overflights but returned to preflight levels within 120 sec. Noise level created did not alter behavior or use of habitat or increase heart rates to the detriment of the sheep.	Heart rate and behavior data suggest sheep habituate to aircraft and the noise they create.
Loehr et al. 2005: *1 month 2001*	yes	*Odd*	n=35 sheep observed	Faro, Yukon Territory; na	recreat.	Obs., Exper.		Thinhorn sheep were observed and subjected to human disturbance trials by hikers.	Females rested less and foraged more under human disturbance and were more vigilant, but not males.	With proper precautions and continued monitoring (to assess whether disturbance becomes more frequent or reactions of individuals change), disturbance of this type can be tolerated by thinhorn sheep.
MacArthur et al. 1982: *na*	yes	*Oc*	n = 5 HRM	Alberta, Canada; na	recreat.	Obs.	Heart Rate	Observed heart-rate-monitored sheep and noted corresponding causes of heart rate elevation.	Cardiac and behavioral responses were ↑ when humans and humans w/ dogs approached from over a ridge. Reactions to road traffic were minimal, no reactions to helicopters or fixed-wing aircraft at distances exceeding 400 m.	Responses to disturbance were detected using HR telemetry that were not evident from behavioral cues alone.
Oehler et al. 2005: *1995-1997*	no	*0c*	n = 19 radio collared	Inyo County, CA; 23.5 km^2	resource extraction	Compar.	VHF	Monitored VHF-collared sheep 1x/week, noted habitat quality at locations, tested pellets for diet quality, surveyed for carnivore scat.	Size of annual HR, composition of diet, and ratios of young to adult females did not differ between sheep inhabiting mined and nonmined areas. Nonmined areas had higher forage biomass than mined sites. In spring sheep near mine had lower forage quality.	Greatest impacts were observed in the summer, recommended either providing alternate water sources away from the mine to mitigate negative impacts or ceasing mining activities during the summer.
Papouchis et al. 2001: *1993-1994*	yes	*Ocn*	n = 42	Canyonlands National Park, UT; 8341 km^2	recreat.	Obs.	VHF	Monitored VHF collared animals and observed non-collared animals along 3km of road and monitored human activities in a high use area and a low use area.	Hikers caused severe responses in sheep (61% fled), vehicles (17%) and mountain bikers (6%). In spring, females in the high-use area fled from hikers >3x farther than females in the low-use area. Alerted up to 363 m from roads. Some sheep habituated to roads.	Hiking has the biggest impact likely because the greater unpredictability of hiker locations. Managers should confine hikers to designated trails during spring lambing and the autumn rut in desert bighorn sheep habitat.
Stockwell et al. 1991: *1985-1986*	yes	*Ocn*	na	Grand Canyon National Park, AZ; na	aircraft	Obs.		Observed desert bighorn sheep from a distance when helicopters were present and absent and recorded behaviors.	Bighorn were sensitive to disturbance during winter (43% reduction in foraging efficiency) but not during spring (no significant effect). Further analyses indicated a disturbance distance threshold of 250-450 m.	Helicopters alter foraging behavior which is most severe in winter. Impacts would be minimized if helicopters were to fly no nearer to bighorn habitat than 500m.

Table 8 Cont.

Author: *Study Duration*	**Peer Re-view**	**Spp.**	**Sample Size**	**Location, Study area size**	**Devel-opment Type**	**Study Design**	**Collar Type**	**General Methods**	**General Results**	**Conclusions & Management Recommendations**
Thompson et al. 2007: *2002-2004*	no	*Ocn*	n = 10	Joshua Tree National Park, CA; 300 km^2	recreat.	Obs.	GPS	Monitored GPS-collared desert bighorn sheep 3x/day. Recreation activity monitored.	Female sheep moved more often, used steeper slopes and areas farther from trails during high levels of human activity resulting in temporarily displacement from habitat.	Access to water and habitat may be temporarily constrained by human activities. Placement of new water sources should mimic historic areas and must support connectivity with other populations. Maintain probable routes between mountain ranges to help prevent isolation.
Weisen-berger et al. 1996: *3 months 1990-1991*	yes	*Ocm*	n = 5 HRM	University of Arizona, Tucson, AZ; small pens	aircraft	Exper.	Heart Rate	Measured heart rate and behavior responses to simulated overflights per day (range = 1-7) and noise levels (range = 92-112 decibels).	34 incidents of increased heart rate in bighorns during 112 overflights and heart rate returned to normal within 60-180 sec.	Sheep were able to habituate rapidly to noise from a simulated jet overflight. Results suggest that bighorn sheep do not view overflights by jet aircraft as a threat.

Notes: Abbreviations are HR, home range; HRM, heart rate monitor; Obs., observational; Exper., experimental; Compar., comparative; recreat., recreation.

Land Use Policies

Patterns of Development

As discussed earlier, almost half the land in the West is public. This limits where and how new exurban residences can be developed. Rather than the classic European pattern of clustered, mixed-use villages (similar to towns commonly found in New England), exurban development has evolved through advances in transportation, amenity migrations and high consumption lifestyles into specific-use, disconnected subdivisions, shopping centers and office parks (Newman 2009). Recent research has indicated that the pattern and rate of growth matter as much or more than the total development footprint (Travis et al. 2005). This is a critical issue as the rate of private land development is over twice the rate of private land protection in the U.S. In Montana, the Subdivision and Platting Act of 1973 was the first law to provide some criteria and a formal process for the division of land (Henderson and O'Herren 1992). However, subdivision growth in areas beyond established communities and in ungulate winter range has continued to occur at sometimes rapid rates, due to weak, fractured and uncoordinated state subdivision laws and local subdivision regulations (Travis 2007). Zoning to manage growth in Montana is an additional local government regulatory tool authorized by state law, but its use is not widespread outside of the larger municipalities. Consequently, a good deal of exurban development and human encroachment into ungulate winter range has occurred with few guidelines and standards regarding suitable location and design (D. Fischer, personal communication).

Recently, 'conservation development' has been proposed as an alternative to conventional sprawl development patterns. It is a tool that allows local governments to protect open spaces, agricultural lands and wildlife habitat from encroachment, while at the same time promoting economic growth (Apel 2011). Conservation development is composed of a variety of site design strategies, including; (1) conservation buyer projects such as conservation easements, (2) conservation and limited development projects which use revenue from limited development to finance land conservation, (3) conservation subdivisions that set aside a major portion of a site for open space and (4) conservation oriented planned development projects which aggregate conservation and development areas at larger scales (Milder 2007). All conservation developments attempt to cluster homes in a small area of a development. This helps to reduce the site-scale impact of a subdivision by minimizing the ZOI around each house (Figure 5). Many handbooks are available in the planning design literature that provide guidelines for developers (for example: Arendt 1996, American Society of Landscape Architects 2009, Washington Department of Fish and Wildlife 2009). However, recent concern over the ability of open space designs to protect important wildlife habitat suggests a need for improved communication between wildlife biologists, landscape architects and planners (Carter 2009, Hostetler and Drake 2009).

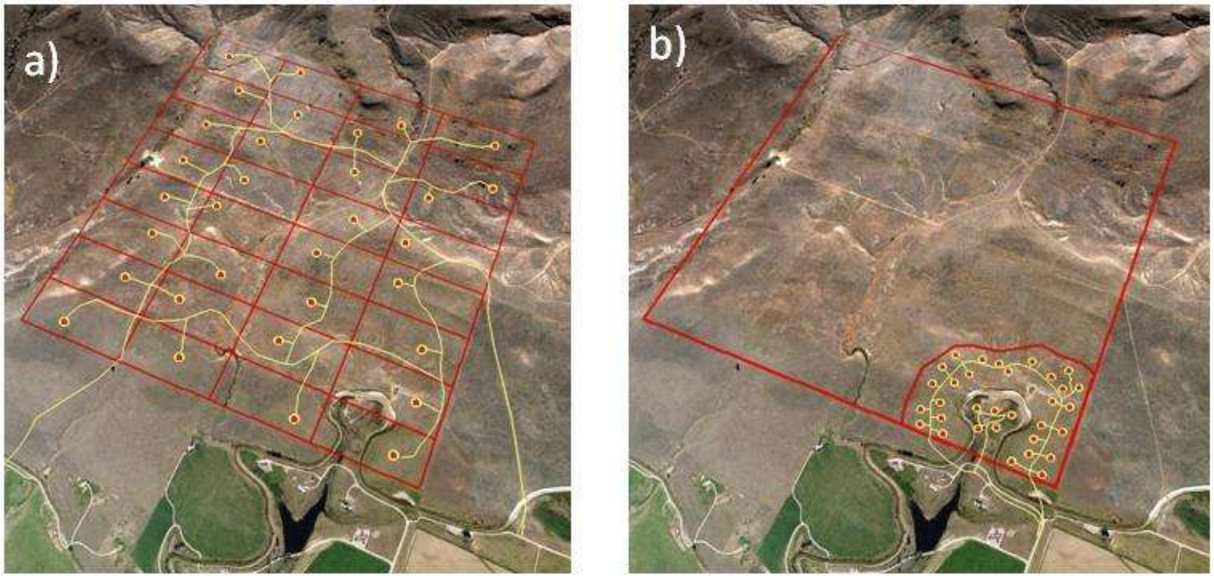

Figure 5. Examples of traditional development of thirty-two 20-acre lots spread across 640 acres of winter range (a), and a “clustered” design (b) of the same 32 houses on 2-acre lots which constitute 10% of the property (64 acres) and are situated in a corner near existing development (J. Vore, figure).

Hostetler and Drake (2009) point out a number of key problems with traditional conservation subdivision designs that bring up new research questions. First, though many development projects inventory species diversity before project implementation, few monitor species during multiple seasons. This is essential to mitigate the effects of development on critical migration stop-over sites, corridors or seasonal habitats such as ungulate winter range. More research is needed to determine how different corridor widths impact ungulate migration patterns at regional and site specific scales (i.e., migration bottlenecks). The potential for wildlife-friendly fencing and road crossing infrastructure to facilitate ungulate migrations also requires more research.

Second, there is a need to regulate habitat configuration, rather than the percent of open space in a development. Protecting a number of small undeveloped units in a parcel increases the amount of fragmentation and edge habitat. Work on songbirds suggests that negative effects of edges can extend into patches up to 200 m and be detrimental to nest success (Maestas et al. 2003, Lenth et al. 2006). On the other hand, protecting large areas adjacent to undeveloped land would provide functional habitat for sensitive species that are often displaced by habitat generalists near developments (Hansen et al. 2005). No research has examined how the design of residential development affects ungulates.

Third, while considerable effort is often put into the design phase of conservation development, less attention has been paid to the physical development and post-development stages. Proper implementation of a conservation plan by contractors is necessary to the success of a project (Hostetler and Drake 2009). Some studies on ungulates have indicated that construction can have a stronger influence on species distributions than post-development (Morrison et al. 1995). However, to date, no studies have specifically examined the influence of residential area construction on ungulates. Questions remain about the ability of ungulates to habituate to physical structures after construction is complete. Further, after development takes place, homeowners must be educated about the importance of open space and made aware that pets, invasive ornamental plant species and recreational use can decrease any remaining wildlife benefits in even the best designed conservation subdivisions. Patterns of residency (i.e., year-round vs. part-time) also likely influence the success of a conservation development projects. Studies on ungulates suggest that both physical development structures and the associated increase in human activity can cause avoidance behavior (Nellemann et al. 2001). Thus, research on the response of specific species to multiple stressors is needed to determine what anthropogenic factor affects ungulates the most.

Currently, most conservation development standards are included in regulations as options which a landowner may choose (e.g., a planned unit development). Such standards are typically not compulsory for development proposals located in wildlife-rich areas. Consequently development frequently occurs outside of zoned areas under the purview of county comprehensive plans, which are advisory only (Travis 2007). Incentives are often used to encourage developers to implement conservation development standards. These commonly include a density bonus that increases the number of units allowed on the property in return for development on a smaller area. Unfortunately, while this type of incentive might decrease the overall human footprint, the intensity and associated human activity in development is greater (S. Reed, personal communication). Another problem with such conservation development standards is that very few require input from ecological experts or plans. Finally, most of these standards last for a set amount of time. This allows development to take place in the conservation area once the project duration is over (for example; only 40 years in Colorado, and 65 years in Wyoming, S. Reed, personal communication). Thus, conservation development standards as currently designed may not be effectively preserving important habitat as well as might be expected at first glance.

Land Use Planning Guidelines

Human encroachment on undeveloped habitat has many negative consequences for wildlife and society. We must be willing to implement sometimes expensive, time consuming and controversial plans to mitigate impacts. As Krausman et al. (2011:189) write, “planning with enforcement has to be a key ingredient or the unplanned, random, and chaotic urban development scheme will continue to alter habitats.” Land use policies are an important tool that can help guide decisions on where to place residential development, how to design developments, and how people can best live in those places. Policies and regulations that incorporate scientific research, ecological principles and land use planning guidelines are essential for successful conservation of important ungulate habitat and migration corridors. Many studies suggest guidelines for monitoring and managing the potential effects of residential development. While most of these guidelines are not specifically directed at ungulate winter range, they are pertinent to maintaining wildlife populations and habitats.

The lack of definitive research on the effects of residential development on ungulates can be frustrating to planners charged with developing effective policies and regulations. Facilitating a direct link between scientific research, ecological principles and land use planning is essential. This requires ecologists and wildlife managers to engage with land use planners to ensure that pertinent research guides large scale development patterns. Planners must proceed on the basis of the most pertinent scientific research as well as the professional opinion of the scientific community. Further, as new information is acquired, guidelines, policies and regulations should be modified accordingly (Duerksen et al. 1996, Environmental Law Institute 2003). It is likely that local governments, neighborhood groups and individual landowners will conceptualize guidelines in very specific ways. Thus, conservation planning needs to be a collaborative and flexible process, and guidelines should represent a starting point that can be modified in response to local variables. In this way land use guidelines can help facilitate the development of policies and regulations needed to guide decisions on how to design developments and regulate their influence on wildlife.

The spatial and temporal scales of the effect of development and the regulation and mitigation of the effect are important to consider when managing wildlife (Johnson and St-Laurent 2011) because land use planning can take place at multiple levels (e.g., individual landowner, local community, county, state, and federal). Mismatches between the scale of ecological processes and land use planning can challenge both scientists and managers (Theobald et al. 2005). Many studies stress the importance of local monitoring because of the complexity inherent to managing individual species that occur in very discrete habitats. Planning at the local or site-level must integrate specific guidelines to promote compatibility between humans and wildlife. A number of specific guidelines can help reduce human-wildlife conflict, support wildlife habitat and reduce habituation at the local scale (Dale et al. 2005, Washington Department of Fish and Wildlife 2009, Estes Valley Planning Commission 2010):

1. Buffer development by the largest area possible
2. Reduce non-native vegetation and the spread of exotic species
3. Reduce fencing or promote wildlife friendly fences
4. Reduce excessive lighting
5. Provide animal proof garbage disposal
6. Control or restrict free ranging domestic pets
7. Focus human impact on resilient areas
8. Maintain large connected patches of undeveloped land
9. Keep zoning densities low within and immediately surrounding high value habitat
10. Manage road systems to minimize the number of new roads and new barriers to important animal movement corridors
11. Include a site level habitat assessment to inform project conditions and management actions

However, because ungulates require large seasonal home ranges and depend on sensitive migration corridors that connect these areas, the best opportunity for conservation of ungulate habitat is at the landscape scale. As research on human impacts accumulates, there is growing focus on ecosystem approaches to monitoring cumulative effects. Ecosystem analysis focuses on ecological resources within natural boundaries and addresses issues of biodiversity and sustainability (Krausman 2011). More importantly, ecosystem analysis considers large landscapes, complex biotic interactions and addresses large temporal and spatial scales; all of which are crucial to understanding the influences of residential development on long-lived, highly mobile ungulate populations. To protect functional winter range, as defined by Montana Fish, Wildlife and Parks, there is a need for collaboration between stakeholders from federal, state, and local government, and private organizations, groups and individuals (Theobald et al. 2005). New innovations in spatial modeling and remote sensing have made conveying alternative land use scenarios to stakeholders across various planning scales possible. This can help determine how incremental development will impact a landscape, an important consideration in cumulative effects assessments. The following principles are useful for protecting habitat in rapidly developing areas at large landscape scales (Duerksen et al. 1996, Krausman 2011):

1. Maintain large, intact patches of native vegetation by preventing fragmentation
2. Establish priorities for species protection and protect habitats that constrain the distribution and abundance of those species
3. Protect rare landscape elements. Guide development toward areas of landscape containing "common" features
4. Use natural boundaries
5. Maintain connections among wildlife habitats by identifying and protecting corridors for movement
6. Maintain significant ecological processes in protected areas
7. Contribute to the regional persistence of rare species by protecting some of their habitat locally
8. Balance the opportunity for recreation by the public with the habitat needs of wildlife
9. Look beyond the life of the project

Table 9. Review of selected scientific literature on exurban development, summarizing study authors, short title, whether the study was peer reviewed or not, study area location, study design, general results and conclusions and management recommendations.

Author: Short Title	**Peer Re-view**	**Study Area location and size**	**Study Design**	**General Results**	**Conclusions & Management Recommendations**
Arendt 1997: Basing cluster techniques on development densities appropriate to area	yes	na	Review	When planning new development, regulations must take into account density of houses. After an appropriate density has been chosen, then housing should be clustered to reduce impact on farmland and conserve habitat.	Guidelines for land conservation include: indentifying conservation areas, special features, locate house sites at a respectful distance from resource lands, align streets and footpaths and set in lot lines.
Beier et al. 2008: Best management for wildlife corridors	no	Arizona	Review	Series of recommendations regarding roads, streams, development and canals in 'linkage' corridors between habitat.	Planners should follow guidelines when developing in corridor areas.
Ben-Ami & Ramp 2005: Modelling the effects of roads and other disturbances on wildlife	no	Australia	Review	Reviewed 4 case studies to find patterns in response to roads and found each population is unique.	Solutions must be location specific. Managers must examine population viability models because road crossings may or may not improve population viability.
Compas 2007: Measuring exurban change in the American West	yes	Gallatin County, MT	Review, Modeling	Major subdivisions have moved closer to service areas, are more clustered and leave more open space. Minor subdivisions are spreading out and taking up more space, thus negating the positive effects of the major subdivision changes. Both types are moving toward riparian areas.	The less consumptive trends of the major subdivisions are cancelled out by the minor subdivisions. Need to initiate more rules on minor subdivisions, more studies on ecological impacts.
Czech 2000: Economic growth limiting factor for wildlife conservation	yes	na	Review	Theoretical paper on why TWS and wildlife professionals should understand economic theory and growth.	Economic development is the limiting factor of wildlife conservation. Wildlife professionals should understand economic growth and take a position.
Dale et al. 2000: Ecological principles and guidelines for managing use of land	yes	na	Review	Land use change can affect 1) species demography and diversity, 2) land cover juxtaposition, 3) disturbance regimes, 4) biological cycles.	Proactive mitigation of land use changes are needed to retain ecological function.
Environmental Law Institute 2003: Conservation thresholds for land use planners	no	na	Review	Patches should be at least 55 ha and some patches should be 2500 ha. 20-50% should be suitable habitat, edge buffers should be 230-300 m, riparian buffers should be at least 100m, a network of corridors should exist. Site specific assessments are always best due to species, topography etc.	More studies need on reptiles, invertebrates and plants in relation to fragmentation. Studies should supply land planners with more concrete guidelines. Land planners should communicate with scientists about what they need.
Estes Valley Planning Commission 2010: Development Review for wildlife protection	no	Colorado	Review	Developers must submit plan, plan is reviewed by division of wildlife for effects on endangered species, calving/lambing/fawning ground, bighorn sheep, raptor nest site and riparian areas. If it does effect these things, developers must have mitigation plan.	Standards should include as large a buffer as possible, no non-native vegetation, no fencing, no excess lighting, animal proof garbage disposal and control of domestic animals.
Glennon & Kretser 2005: Impacts to wildlife from low-density exurban development	no	na	Review	Majority of articles on high density development. Fragmentation has varying effects on species but almost always a negative effect on biodiversity. Maintain up to 6 km buffer for some nesting bird spp.	Clustered and conservation subdivisions may mitigate some impacts but aren't a catchall. More studies need to be done on exurban development specifically, seasonal homes, and people’s perception of wildlife.

Table 9 Cont.

Author: Short Title	**Peer Re-view**	**Study Area location and size**	**Study Design**	**General Results**	**Conclusions & Management Recommendations**
Gude et al. 2006: Rates and drivers of rural residential development in the Greater Yellowstone	yes	GYE; 145635 km2	Review	Private lands are generally in valley bottoms close to water and have been since 1900. Proximity to national parks raises chance of development. Towns with higher educated population had higher rates of development.	Private lands are generally found in winter ranges and areas important to wildlife for migration in the GYE. Counties need stricter land use regulations in order to control development and steer it in an ecologically sound direction.
Gude et al. 2007: Biodiversity consequences of alternative land-use scenarios in Greater Yellowstone	yes	GYE; 145635 km2	Modeling	Riparian habitat, elk winter range, migration corridors are likely to undergo substantial conversion (between 5% and 40%) to exurban development by 2020. Future exurban development outside the region's nature reserves is likely to impact wildlife populations within the reserves.	Most habitats are likely to experience 10-40% change in next 10 years, but growth management can influence pattern. Counties should implement zoning plans for conservation, conservation easements and apply incentives for growth near towns.
Hansen et al. 2005: Effects of exurban development on biodiversity	yes	the West	Review	Urban fringe development and rural residential development effect biodiversity in multiple ways, not always linear. Usually an increase of non-native species and decrease of non-adaptable native species. Decrease in biodiversity due to habitat alteration, ecological process alteration, biotic interaction alteration and human disturbance.	Need to study the patterns and mechanisms of exurban development so mitigation is more effective.
Hawbaker et al. 2006: Road development, housing growth and landscape fragmentation	yes	Northern WI; 1564 km2	Modeling	From 1939-1960 road density more than doubled, area affected by roads doubled, max roadless patch decreased by 1/2, mean and median patch sizes decreased 4 fold. First roads in area contributed more to habitat fragmentation than later roads.	Road density has increased and has changed the ecological landscape and probably the behavioral patterns of wildlife in the landscape. Limit early road construction. Construct under and overpasses to reduce fragmentation, remove unused roads.
Jarvis 2008: Residential development patterns in Flathead County, MT	no	Flathead County, MT; 13603 km2	Review, Modeling	The number of new residential parcels has increased. Distance to roads and home density are significant predictors of residential development.	Flathead county has a lot of exurban development. Almost everywhere is scenic so amenities were not significant in predicting development.
Knight et al. 1995: Ranching the view: subdivisions vs agriculture	yes	the West	Review	Patterns of land use in West show that subdivisions occur in valley bottoms, which are important habitat for many animals. Problems include roads, buildings, fences, noise, human presence, lights, exotic species, domestic predators.	Subdivisions are affecting biodiversity and ecosystems to a high degree in the West.
Kretser et al. 2008: Housing density as an indicator of spatial patterns of reported human-wildlife interactions	yes	Northern NY near Adirondack Park; 46000 km2	Modeling	Housing causes decline in biotic integrity. Human-wildlife interactions cluster in areas dominated by suburban and exurban housing densities compared to urban and wildlands. Low density developments have higher reported human-wildlife interactions. Reports of black bears increased within the wildland areas.	Suburban and exurban densities are the primary locations where interactions between humans and wildlife are reported. Developments should be clustered to minimize the influence of each house. More densely settled areas would reduce human-wildlife interactions. Focus outreach on specific human wildlife issues within particular land use densities.
Kretser et al. 2009: Factors affecting perceptions of human–wildlife interactions	yes	Northern NY near Adirondack Park; 24000 km2	Survey	People with a negative outlook on wildlife were older, lower income, lower knowledge of wildlife, and had fewer interactions with wildlife. People from urban backgrounds were more likely to have positive experiences with wildlife compared to rural backgrounds. People were more likely to support programs protecting wildlife and land if they had a positive experience with wildlife.	People with negative experiences were more likely to return the survey, but less likely to contact professionals about wildlife issues, thus reporting appears inconsistent with negative perceptions. Moose and deer had more positive perceptions than smaller "pest" species. Managers should focus on ways to increase positive interactions with people and wildlife (bird watching or photography). Need species specific policies for better communication with public.

Table 9 Cont.

Author: Short Title	Peer Re-view	Study Area location and size	Study Design	General Results	Conclusions & Management Recommendations
Lenth et al. 2006: Conservation value of clustered housing developments	yes	Boulder, CO	Observational	Clustered development was more similar to dispersed development than to undeveloped lands in species composition of both wildlife and plants.	Outlots were not large enough to compensate for development. Half of land was within buffer. Need to make outlots larger, cluster homes closer together and far from sensitive areas. Promote native landscaping and manage outlots for native species (ie control pets/people onto trails, promote native veg).
Maestas et al. 2001, 2003: Biodiversity across a rural land use gradient in the American West	yes	Larimer County, CO	Compar-itive	Biodiversity was higher on ranches and protected areas than in exurban areas. Non-native plants and human-adapted spp were highest in exurban development, some, including noxious weeds and nest predators seen only in exurban.	Exurban development could be eco-sink for wildlife and source for noxious spp and nest predators. Exurban development has profound effects on biodiversity. Conservation easements should be continued on ranches since private lands can have higher spp richness than protected areas.
Peterson et al. 2008: Household location choices: Implications for biodiversity conservation	yes	Teton Valley, ID/WY	Survey	Large differences in environmental attitude and reasons for household location between immigrants and natives. Older, more educated, more environmental and richer people were living in natural areas.	Environmentally friendly attitudes may lead to more exurban development. Need to educate people on the effects of their household choices.
Radeloff et al. 2005: The wildland-urban interface in the United States	yes	United States	Modeling	WUI is greatest in the east and in California. In Montana it is a high percentage of all houses but not a high percentage of land.	Fires are a growing problem with WUI houses as well as habitat fragmentation and degradation. Need to take ecology into consideration when developing.
Theobald 2005: Landscape patterns of exurban growth in the USA	yes	United States	Modeling	Exurban development is increasing faster than any other kind. 10-15% growth/year. Exurban development has a larger ecological footprint than urban and suburban development.	Ecologists need to know thresholds in each ecosystem for how much development can occur.
Theobald et al. 1997: Estimating the cumulative effects of development on wildlife habitat	yes	the West	Modeling	Clustered development had the lowest ZOI, but linear clusters could create a lot of fragmentation.	Well designed clustered development should be used to mitigate effects of development on wildlife.

Notes: Abbreviations are GYE, Greater Yellowstone Ecosystem.

Conclusions

They come from all over, modern-day migrants fleeing freeways, smog and crime, yearning for their own little piece of the West. And with each new arrival, there is that much less of the wide open space they all crave. The American West is torn between two visions of one place. Although many cling desperately to the Old West ethos of a hardworking people who came to tame the land and tap its wealth, other are just as determined to bring on a New West, where nature is no longer ravaged, but restored. Yet, before the West can choose between Old and New, this stream of new settlers could doom them both. . . . Amid all the clamor over mining and grazing, grizzlies and wolves, [there is] something more troubling. . . . ***The single most dramatic resource issue we face, and I mean really immediately, is people.***

(Diringer 1994, quoted in Shumway and Otterstrom 2001)

This review attempts to draw attention to the potential impacts the conversion of undeveloped land into residential structures has on habitat, behavior, population dynamics and management of ungulates. Only 22 papers reviewed specifically examined the effects of residential development on ungulates. Not one of the studies was a replicated experiment that rigorously analyzed the population-level impacts of development on ungulates species. This is a concerning result since the demand for new residential spaces is likely to increase in the coming decades in response to a growing human population in the West (Theobald 2005, Compas 2007, Gude et al. 2007).

The threat of unplanned, unregulated development on ungulate winter range should be a real concern to managers, policy-makers and the general public who appreciate and value native ungulates in the West. The effects of exurban development on wildlife may even exceed those of energy and resource extraction activities in some areas in part due to the lack of regulatory oversight and enforceable policies relating to new housing developments. Although no cause and effect studies documented the early influence of residential development on ungulate winter range during the past century, it is probable that this encroachment played a fundamental role in historic mule deer, elk, pronghorn and bighorn sheep declines in the West. Certainly, the low-elevation valleys and mountain foothills that are now occupied by western cities and towns were once vital winter ranges to a variety of ungulate species. **Though we cannot return these areas to pre-European settlement conditions, we can manage new growth to ensure that ungulates remain a significant part of the western landscape.**

Most ungulates exhibit short-term behavioral reactions in response to human disturbance. Many of these responses have been summarized in previous literature reviews (Canfield et al. 1999, Frid and Dill 2002, Hebblewhite 2008, Stankowich 2008, Parker et al. 2009). However, very few studies link short-term behavioral reactions to population-level consequences. This is unfortunate, because these inferences are needed to evaluate the effectiveness of management strategies, understand and predict the effects of development and monitor regulatory requirements. Evaluating the potential population-level responses of ungulates to residential development is further confounded by historic broad-scale population declines that make isolating the interacting influences of a range of synergistic factors difficult. Several recent long-term monitoring projects on the effects of energy development on ungulates suggest that demographic impacts may take many years to detect (Beckmann and Seidler 2009, Sawyer and Neilson 2010). As discussed by Hebblewhite (2008), short (2-5 year) studies simply do not have the statistical power to detect changes in vital rates. Compensatory reproduction and resilience in adult age-cohorts can create time lags between the effects of development and the eventual impact on the population. Further, ungulates are large, highly mobile species. They can, and will, adapt to predictable human disturbance through behavioral adaptations that can mitigate negative consequences on vital rates, at least in the short-term and within theoretical development thresholds. Thus, there is a pressing need for long term cumulative effects studies that can clarify the mechanisms driving changes in abundance and distribution.

Both direct and indirect impacts can result from increased human development, activity and infrastructure. Avoidance is defined as a reduction in use compared to what would be expected based on availability. Thus, it is important to note that avoidance does not indicate that ungulates never occur near developments, but rather, areas near developments are used less than expected. In general, for mule deer, elk, pronghorn and bighorn sheep, the avoidance ZOI extends well beyond human developments, though responses vary between species, development types and seasons (Tables 4, 5, 6, 7, and 8). In general, ungulates tend to avoid roads when human activity is highest, which is often during the summer (Hebblewhite 2008). Regardless of the actual percent decrease in use around developments, even a modest ZOI can result in large amounts of habitat becoming functionally lost due to indirect avoidance (Polfus 2010). The increase in GIS remote mapping capabilities and numbers of GPS collared animals will make determining how ungulates avoid various anthropogenic disturbances easier in the future. A large-scale habitat analysis of GPS location data from 581 radio-collared boreal woodland caribou (179,022 locations from 2000-2010) distributed across Canada indicated that caribou consistently avoided high road density and recent burns (Polfus and Hebblewhite 2010). Similar assessments that utilize GPS location data from published studies of elk, pronghorn, mule deer and bighorn sheep across a gradient of human land use densities could improve our understanding of the large-scale response of ungulates to residential development.

Making comparisons across studies of species responses to development can be difficult due to differences in methodology, techniques, regulatory measures, and the scale of the impact examined (Johnson and St-Laurent 2011). Specifically, defining minimum patch sizes and buffers around residential structures is difficult due to extensive variation in habitat quality, the proximity to forests and escape and hiding cover, the presence of predators, the occurrence of hunting by humans and competition with other ungulate populations. Perhaps most importantly, different research designs and metrics used to assess an effect will alter the detection of impacts. This discrepancy has lead to political and scientific controversy regarding the effect of human activity on ungulates, especially when stakeholders have a vested interest in the interpretation of avoidance distances (Wolfe et al. 2000). Further, results are also sensitive to the criteria used to define a metric. For example, the minimum patch size might relate to the area required to maintain species as measured by occurrence, population densities, survival or reproductive success. More space would likely be needed to maintain a large population that could tolerate environmental stochasticity while a smaller area could support a population during only one season. A literature review conducted by the Environmental Law Institute (2003) found only 20 papers that provided enough information to determine minimum patch area requirements for all wildlife species and none were specific to ungulates. Few studies have examined how much area is required to maintain species diversity or ecological community dynamics.

Of the studies reviewed on the effects of residential development on ungulates, the majority focused on white-tailed deer. These studies almost all occurred in the midwestern and eastern United States and, in general, concluded that white-tailed deer commonly habituate to human presence in suburban areas. There are likely large behavioral differences between highly habituated white-tailed deer in the eastern United States where available undeveloped habitat is a limited resource, and deer in the West that use large expanses of undeveloped land (Hoekman et al. 2006). However, even in western cities, white-tailed deer abundance can exceed human tolerance, threaten human safety through deer-vehicle collisions and conflict with personal property.

Only 5 studies on mule deer and 4 studies on elk analyzed populations in relation to residential development. Results of these papers are inconclusive. In general, mule deer show some avoidance of residential areas, but studies were based on indexes of distribution and all had low samples sizes (Smith et al. 1989, Vogel 1989, McClure et al. 2005). However, high densities of sedentary mule deer and elk in urban areas have been linked to increased rates of disease (Farnsworth et al. 2005, Olsen 2010). Two studies on elk found behavioral avoidance of residential development (Wait and McNally 2004, Cleveland 2010), while alternatively Hebblewhite et al. (2005) and Kloppers et al. (2005) studied a habituated elk herd that was adapted to the urban area of Banff, Alberta. However, many studies indicate that mule deer and elk avoid roads, industrial infrastructure and recreation. While behavioral avoidance behaviors have not been specifically tied to population-level responses in most cases (exception being the long term study by Sawyer and colleagues in southwest Wyoming), increased vigilance, flight and behavioral avoidance, have the potential to increase energy expenditures and could result in population declines, especially during severe winters. Migratory behavior in elk and mule deer also make protecting migration corridors important.

No studies have specifically examined the impact of residential development on American pronghorn or bighorn sheep. However, historic declines in both species are likely due to expansion of residential development, resource extraction, competition with domestic livestock and habitat fragmentation. Like other ungulates, both pronghorn and bighorn sheep exhibit a number of overt behavioral reactions in response to human disturbance which can increase energy expenditure. Barriers to movement, especially in pronghorn migration corridors, are a crucial threat to population persistence (Sawyer et al. 2005). Mitigating the effects of residential development that occur in critical migration bottlenecks should receive the highest conservation priority. Bighorn sheep continue to be subject to disease transfer from domestic livestock where habitat overlaps rangeland (George et al. 2009). In general, bighorn sheep and pronghorn populations require large-scale, multi-jurisdictional initiatives to protect critical migration corridors and winter ranges.

Ungulates can habituate to temporally and spatially predictable human activity especially when not hunted or harassed. These problem animals reduce the flexibility of managers to control ungulate populations through hunting quotas and weaken public enjoyment of wildlife. Further, negative interactions between problem wildlife and humans in residential areas can undermine public support for management agencies and conservation initiatives (Kretser et al. 2009). Habituated ungulates may display a decrease in migratory behavior, overgraze winter ranges and move to private lands or urban areas where hunting is not allowed. As more valley bottom lands are transferred from hunter-friendly ranches to subdivisions, the amount of land used as refuge by ungulates during the hunting season is likely to increase. This results in an ineffective and costly use of resources and reduces the ability of management agencies to control ungulate populations.

Finally, unregulated exurban development also poses a threat to human health, safety and public wellbeing. Subdivisions built in highly scenic areas, far from towns, stress public services and facilities, decrease the efficiency of roads and utility lines and increase the tax burden on county residents (Gude et al. 2006). Rural residential areas disrupt natural disturbance regimes and are at high risk for wildfire damage. Development trends suggest that new residential areas will continue to be built in high quality ungulate winter range. **As a society we walk a delicate line between enjoying the numerous traits of the wild places we value and destroying them with our presence.**

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Management Implications

Understanding human expectations is critical to managing wildlife in proximity to human developments. As has been discussed before, successful management of wildlife depends on effective management of people (Krausman et al. 2011). The problems that face managers today are too complex to be solved by biologists or managers alone. Thus, it is important to acknowledge the limitations and biases associated with scientific research and recognize the importance of ethics and social justice in environmental problems. Specific to ungulates responses to development, this review suggests similar management recommendations to Hebblewhite (2008):

1) Short-term and small-scale behavioral impact studies on the effects of human development on ungulates are pervasive in the literature. Most studies are observational and infer the impact of development by correlating behavioral responses to human developments. This is generally the weakest study design and makes determining cause and effect difficult (Hebblewhite 2008). In general, mule deer and elk tend to avoid human activity near residential developments. Pronghorn and bighorn sheep display avoidance of other forms of human development and recreation. White-tailed deer are able to adapt to high levels of human activity near residential areas in the midwestern and eastern United States. Large scale multi-jurisdictional studies that utilize all available GPS location data from the published literature may help improve our understanding of the response of ungulates to residential development.

2) There is a need for long-term cumulative effect studies that monitor population level responses to the increasing growth of residential areas in the West. Ungulate persistence is unmistakably dependent on available habitat – habitat which is quickly being compromised by extensive development across the American West. The scale and incremental process of piecemeal development further confounds the ability of land planners to address cumulative effects. Single development permits, authorized over the span of years can make it difficult for review boards and planners to decline building permits when an area already contains multiple houses (Travis 2007). It is unlikely, especially when considering the historic large-scale declines in ungulates in the last century, that populations will be able to withstand this type of persistent gradual development. Thus, the cumulative impact of multiple low-density residential developments can be expected to produce significant ecological effects over time.

3) No studies have rigorously analyzed the population-level impacts of residential development on ungulates species. This is unfortunate, because the demand for new residential developments in the West is likely to increase in the coming decades in response to a growing human population. However, two long-term studies on the effects of energy development on pronghorn and mule deer suggest > 5 years of monitoring is needed to detect population level responses (Beckmann and Seidler 2009, Sawyer and Neilson 2010). The methods described in these studies can provide a framework for new research on the effects of cumulative residential development across the Rocky Mountain West. Because information is currently lacking on specific guidelines, managers should use **adaptive management** to test how new residential developments affect ungulate winter range.

4) Wildlife managers, ecologists and science providers or academics should be encouraged to engage in the land use planning process to ensure that pertinent research is integrated into regulations and policies. For example, wildlife biology students should be required to take classes in applied conservation biology that cover topics such as communication skills, stakeholder partnerships and local land use planning initiatives (Cleveland et al. 2009). Managers and academics should be encouraged to work with local communities, understand the desires of stakeholder groups and allow alternative management scenarios to be discussed (Lee and Miller 2003). Educating and including the people affected by management actions in the decision-making process will result in better implementation of plans on the ground.

Appendix A

Table A-1. Additional studies on the effects of human disturbance on ungulates, summarizing study authors, short title, species (Rtt-*Rangifer tarandus tarandus*, Rtc-*R. t. caribou*, Rtg-*R. t. granti*, Oa-*Oreamnos americanus* (mountain goat), Aa-*Alces alces*, Ov-*Odocoileus virginianus*, Ovc-*O. v. clavium* (Florida Key deer), Od-*O. hemionus*, Oc-*Ovis canadensis*, Ce-*Cervus elaphus*, Ua-*Ursus arctos*), whether the study was peer reviewed or not, study area location and size, development type, study design, study size, general results and conclusions and management recommendations.

Author: Short Title	***Spp***	**Peer Re-view**	**Study Area location and size**	**Development Type**	**Study Design**	**General Results**	**Conclusions & Management Recommendations**
Andersen et al. 1996: Short term behavioural and physiological response of moose to military disturbance	*Aa*	Yes	Norway; 1,600 km^2	Human disturbance	Before/after, n=4 heart rate monitors and n=12 radio collared	Sources of disturbance which can be identified as human trigger flight responses at greater distances, and elevate heart rate for longer periods, than those recognized as mechanical.	Military activity of the type studied here is not especially detrimental to moose, and that the effects of their activity should not differ from comparable civilian harassment.
Berger 2007: Fear, human shields and the redistribution of prey and predators in protected areas	*Aa, Ua*	Yes	GYE; 500 km^2	Roads and human activities	Comparative, n=192 radio collared	Moose selected to be closer to human activity as grizzly bear predation increased. Grizzly bears avoided human activity, providing a human-caused refugia from predation.	Effects of human activities on wildlife can be counter-intuitive in the presence of human-caused refugia from predation. Considering indirect effects of trophic interactions to gauge development impacts key.
Bradsaw et al. 1997: effects of petroleum exploration on woodland caribou	*Rtt*	Yes	Northeastern AB; 20,000 km^2	Simulated Seismic explosions	Experimental, n=23	Exposed animals showed higher mean movement rate; no effect of distance from animal to canon vs. movement; exposed animals showed higher habitat patch change; exposure to sound reduced feeding time.	Total avoidance of winter petroleum exploration rather than shorter activity restrictions
Burcham et al. 1999: Elk use of private land refuges	*Ce*	Yes	Western Montana; na	na	Observational, n = 66 (1st period), 39 (second period)	Almost all of one herd used private land refuge during hunting and at least 75% of the other, use of private land is increasing, use is mainly during hunting season.	Try to implement special hunts on private lands, work with landowners to prevent overabundance.
Canfield et al. 1999: Effects of recreation on Rocky Mountain wildlife: ungulates	*ungulates*	No	the West	na	Review	Erratic behavior is more distressing than constant, snow is deciding factor for winter range, lower metabolic rates in winter. Bighorn are most vulnerable to humans, elevated heart rates = metabolic increase even without flight.	Managers should project winter range from recreation, more studies should be done on spring migration routes for regaining weight lost during the winter.
Christianson & Creel 2007: A review of environmental factors affecting elk winter diets	*Ce*	Yes	Western North America; na	na	Review	Elk prefer graminoids even when they are less abundant. Elk use open range less in hard winters, use more browse when hunted. Graminoids may not be the most nutritious but elk across North America prefer them.	Important to understand what elk will prefer especially when other environmental factors might affect winter range.
Colescott & Gillingham 1998: reaction of moose to snowmobiles	*Aa*	Yes	Wyoming; 0.04 km^2	Snowmobiles	Observational, observations from blinds	Snowmobile traffic did not appear to alter moose activity significantly though it did influence the behavior of moose within 300m of the trail and displaced moose to less favorable habitats.	Restrict the timing of snowmobile use to mid day when moose are resting.

Table A-1 Cont.

Author: Short Title	***Spp***	**Peer Re-view**	**Study Area location and size**	**Development Type**	**Study Design**	**General Results**	**Conclusions & Management Recommendations**
Cote 1996: mountain goat responses to helicopter disturbance	*Oa*	Yes	Alberta; 21 km^2	helicopter (energy exploration)	Observational, n=14 radio collared n=98 marked	Goats showed overt responses to 58% of helicopter flights within 2 km. When helicopters flew within 500 m, 85% of flights caused the goats to move >100 m or to be alert for >10 min.	Recommended avoiding helicopter flights within 2 km of mountain goat habitat.
Dahle et al. 2008: reindeer avoidance of highways	*Rtt*	Yes	Norway; 8,200 km^2	highways and cabins	Observational, lichen sampling	Lichen height decreased 35% over an 8km distance from the highway and cabin indicating avoidance of highway.	Wild reindeer tolerance towards human infrastructure varies spatially and is influenced by herd traditions and/or motivation to follow established migration corridors.
DeCesare & Pletscher 2006: Movements, connectivity and resource selection of bighorn sheep	*Oc*	Yes	Western Montana, na	na	Observational, n = 21	Females had high fidelity to home range, but males moved more, including over highway/river, escape terrain is consistently important, but variation in habitat made other factors inconsistent (including roads).	Movement suggests more genetic and disease connectivity between populations than previously thought. Managers need to use local models.
DeNicola et al. 2000: Managing white-tailed deer in a suburban environment	*Ov*	No	na	na	Review	Management can occur at small group level because deer have high fidelity to matrilineal groups/ranges and wont colonize very quickly. New management strategies need to be community wide programs with a lot of information passed between parties.	There are a number of options for management in high density development areas, some lethal, some non-lethal. Need to make local plans to manage deer keep good relationships around the community.
Dyer et al. 2002: barrier effects of roads and seismic lines of woodland caribou	*Rtc*	Yes	Northern AB; 6000 km^2	roads and seismic lines	Observational, n=36	Roads were barriers to movement especially in late winter and seismic lines were not barriers. Functional habitat loss through avoidance.	Approach useful in quantifying animal movements.
Dyer et al. 2001: Avoidance of industrial development by woodland caribou	*Rtc*	Yes	Northern AB; 6000 km^2	roads, seismic lines, pipelines	Observational, n=36	Seismic lines were semi-permeable barriers to caribou movements, roads were barriers with high traffic. Caribou avoided human development by 250 – 1000 meters (seismic vs wells). 22% - 48% of study area impacted by roads.	Semi-permeable barrier effects may exacerbate functional habitat loss through avoidance behavior. Effects great year round.
Foster & Rahs 1985: canyon-dwelling mountain goats in relation to a proposed hydroelectric develop.	*Oa*	Yes	Northwest BC; n/a	Hydro-electric exploration activities	Observational, observed goats and n=56 marked with dye and neck collars	Mountain goats shifted their distribution 1 km - 3 km when subjected to drilling disturbances fully visible from escape terrain, but they returned when the disturbance was removed.	Recommended a 2km buffer to prevent an overt disturbance response to human activity
Garrett & Conway 1999: Characteristics of moose-vehicle collisions	*Aa*	Yes	Anchorage, Alaska	Vehicle collisions	Observational, data from moose collisions	Collision rate increased during the study period from 40 to 52 MVCs per 100,000 registered vehicles in Anchorage. Collisions were 2.6 times more likely to have occurred in the dark	Reduce speed limits around greenbelt areas, brighter vehicle headlights, placement of street lights in known moose areas, underpasses at known crossings, and snow removal to reduce berm height in areas of high moose concentrations.
Haggerty & Travis 2005: Out of administrative control: Absentee owners, resident elk	*Ce*	Yes	Paradise Valley, MT; 971.25 km^2	ranches	Survey, Modeling	Attitudes toward elk and hunting as a management tool have changed and resulted in an increasing elk population.	Elk are benefiting from a change of landownership from full time ranchers to part time nature enthusiasts. Hunting is no longer an effective strategy to manage the herd as a whole since they are spending so much time on private lands.

Table A-1 Cont.

Author: Short Title	***Spp***	**Peer Re-view**	**Study Area location and size**	**Development Type**	**Study Design**	**General Results**	**Conclusions & Management Recommendations**
Harveson 2005: Impacts of urbanization on endangered Florida key deer	*Ovc*	No	Florida Keys, FL; 98.36 km2	urban	Observational	Key deer are more urbanized now than 30 years ago, positive relationship between spending time in urban areas and survival, deer now prefer urban areas, as urban use increases, flight response distance decreases.	Key deer have adapted to urban environment. There is probably a threshold of urbanization that key deer cannot withstand, roads should be protected to lower the mortality from cars.
Hebblewhite et al. 2006: Is the migratory behavior of montane elk herds in peril?	*Ce*	Yes	Alberta; 6000 km^2	na	Observational, n = 81 VHF, 20 GPS	Ratio of migratory to residential elk has declined. Change in migration is most likely due to winter range enhancements, habituation to hay feeding and wolf protection in Banff NP.	Managers should be alert to changes in migration since it's so important to ecosystem, need to work to provide better transboundary management schemes.
Hebblewhite et al. 2009: Trade-offs between predation risk and forage differ between migrant strategies	*Ce, Cl*	Yes	Banff National Park; 7000 km^2	ranches	Observational, n = 109 adult female elk	Migration reduced exposure to wolf predation risk by 70% compared to residents. Migrants had 6% higher digestible forage. Residents reduced predation at fine scales by using areas near humans.	Resident elk maximized forage by feeding on high quality forage near humans to reduce predation risk. Predator exclusion because of high human activity reduced predation rates by wolves by 60%. Human activity can disrupt predator-prey dynamics.
Henderson & O'Harren 1992: Winter ranges for elk and deer: un-controlled subdivisions?	*Ov, Oh, Ce*	No	Montana	na	Review	Winter range is quickly being developed to the detriment of MT's natural resources and wildlife.	Subdivision laws are not strict enough, too many exemptions. Conservation easements are a good way to protect habitat. Local government must get involved.
James & Stuart-Smith 2000: Distribution of caribou and wolves in relation to linear corridors	*Rtt*	Yes	Northeastern AB; 20,000 km^2	roads, trails, seismic lines, pipelines	Observational, n=98	Caribou mortalities attributed to wolf predation were closer to linear corridors.	Development of new corridors within caribou habitat should be minimized. Existing corridors should be made unsuitable as travel routes to reduce impacts.
James et al. 2004: spatial separation of caribou from moose and its relation to wolves	*Rtt*	Yes	Northeastern AB; 20,000 km^2	Oil and gas, seismic lines	Observational	Caribou avoided habitats selected by wolves and moose, but moose preferred habitats impacted by forestry.	Limit overlap of energy and forestry development with spatial refuge areas for caribou.
Johnson et al. 2005: Cumulative effects of human developments on arctic wildlife	*Rtg*	Yes	Northwest Territories; 190,000 km^2	Energy exploration, hunting, mines.	Observational, n=28	Mines had the largest negative effect on species. During post-calving caribou had a 37% reduction in the area of the highest quality habitats and an 84% increase in the area of the lowest quality habitats.	Regional cumulative effects analyses serve as the coarsest framework for understanding the impacts of human developments on wide-ranging animals.
Joslin 1986: mountain goat population changes in relation to energy exploration	*Oa*	No	Montana; 823 km^2	Energy exploration, Seismic lines	Observational, n=24 radio collared, n=8 neckbanded	Significant decline in numbers of adult females, kids, and productivity that coincided with a peak in seismic/exploration activities by energy industry.	Efforts should be made to reduce human activities in the Teton-Dupuyer segment in order to allow goat populations to recover.
Kunkel & Pletscher 2000: Habitat factors affecting vulnerability of moose to predation by wolves in BC	*Aa*	Yes	Southeastern BC; na	logging and wolf predation	Observational, n=29 radio collared	Moose density was greater and hiding-cover levels were lower at kill sites than at control sites. Forest harvest practices in this study area apparently did not increase the vulnerability of moose to wolf predation.	Moose are less likely to be killed by wolves at higher elevations, farther from trails, away from other moose, nearer to or within areas sheltered by large trees, and in areas with higher road density.

Table A-1 Cont.

Author: Short Title	***Spp***	**Peer Review**	**Study Area location and size**	**Development Type**	**Study Design**	**General Results**	**Conclusions & Management Recommendations**
Lauber 2010: Community-based deer management	*Ov*	No	New York	na	Survey	3 barriers to deer management: inadequate stakeholder engagement, a decision-making process that was ineffective at promoting information exchange and dialogue, and lack of leadership.	Used 3 terms: power, legitimacy, and urgency to describe the situation in each town. When these 3 things work with stakeholders as well as good leadership, it is easier to come to conclusions.
Lee & Miller 2003: Managing elk in the wildland-urban interface	*Ce*	Yes	Flagstaff, AZ	na	Survey	People like seeing elk, concerned about vehicle collisions, not concerned about property damage. Very concerned about hunting b/c of human safety, increased oversight of urban hunt could allay fears.	People could be convinced of urban hunting with the right controls. Find out what the population wants for urban wildlife, make sure to address their concerns.
Mahoney et al. 2001: Caribou reactions to provocation by snowmachines	*Rtc*	Yes	Newfoundland; 1,805 km^2	snowmobiles	Observational, approached groups	Snowmobiles displaced caribou from resting activities and initiated avoidance reactions that interrupted feed bouts and increased locomotion rates. Displaced 60-237m from initial locations.	Variation in response by individuals and across years must be taken into account.
Nellemann et al. 2001: Winter distribution of wild reindeer in relation to power lines, roads and resorts	*Rtt*	Yes	Norway; 2900 km^2	Roads, railroads, power lines	Observational, n=2500	Density of reindeer was 79% lower within 2.5 km from power lines compared with background areas. Areas within 5km of development were avoided in all years.	Construction of roads, power lines and cabin resorts endanger the available winter ranges of reindeer in southern Norway.
Nellemann et al. 2003: Progressive impact of piecemeal infrastructure development on wild reindeer	*Rtt*	Yes	Norway; 1350 km^2	Hydroelectric development	Comparative, before, during, after development n=>2000	Reindeer densities within a 4km radius to infrastructure declined during winter and summer with a 217% increase in use of the few remaining sites located >4km from infrastructure.	Controlling piecemeal development in infrastructure is critical for the survival of the remaining European populations of wild mountain reindeer.
Nelson 1998: migratory behavior in northern white-tailed deer	*Ov*	Yes	Superior NF, MN; 2500 km^2	na	Observational	Fawns generally followed the migratory pattern of their mothers, but could and did change.	Migratory deer is a learned social pattern and not genetic.
Pedevillano & Wright 1987: The influence of visitors on mountain goat activities	*Oa*	Yes	Glacier NP, MT; na	human disturbance	Observational	Park visitors did not disturb goats enough to stop them from using licks but people on overpasses and traffic did scare goats away from crossing highways.	All crossings were eventually successful. Before underpass made goats ran back 44% of the time, after underpass only 24% of the time
Polfus et al. *in review*: Identifying indirect habitat loss and avoidance of human infrastructure by caribou	*Rtc*	*in review*	Atlin, northern BC; 11594 km^2	human development	Observational, n = 10	Caribou avoided 2 km around high use roads and 1 km for low use roads. In winter, caribou avoided town by 9 km compared to 3 km in summer. In winter avoidance of mines (250 m) and no avoidance of cabins. In summer caribou avoided mines by 2 km and cabins by 1.5 km.	Seasonal habitat models indicated that high quality habitat in the vicinity of human development was used by caribou less than expected. Conservation efforts should prioritize protecting areas of high quality habitat within human zone of influence.
Reimers et al. 2003: Behavior responses of wild reindeer to snowmobile or skier	*Rtt*	Yes	Norway; 5700 km^2	snowmobiles and skiers	Observational	Reindeer responded to snowmobile disturbance on average 164m further away than skiers. Mean flight distances were 281m from skiers and 264m from snowmobiles.	Restrict recreational use of snowmobiles.
Reimers et al. 2006: flight by reindeer in response to approach on foot or skis.	*Rtt*	Yes	Norway; 2,000 km^2	Human approach	Observational, approach reindeer groups	The farther away the person was when first sighted, the greater the distance of flight. This response was greatest in July and least in September-October during rut.	Humans stay 350m away from reindeer from March-July and 200m in September-October. Human approach did not appear to cause substantial energy costs to reindeer in this system.

Table A-1 Cont.

Author: Short Title	***Spp***	**Peer Re-view**	**Study Area location and size**	**Development Type**	**Study Design**	**General Results**	**Conclusions & Management Recommendations**
Schneider & Wasel 2000: The effects of human settlement on moose density	*Aa*	Yes	Northern AB;3 76,224 km^2	Human settlement	Observational, aerial surveys	At the regional scale the density of moose was positively associated with the density of roads. The regions with the greatest moose densities also had the greatest intensity of licensed hunting.	↑ densities of moose were observed in association with a highly fragmented landscape with substantial agricultural, implying that moose requirements for cover may be quite flexible, at least in regions where snow fall is not extreme.
Seip et al. 2007: Displacement of mountain caribou From winter habitat by snowmobiles	*Rtc*	Yes	Southeastern BC, na	snowmobiles use	Observational, n=28 radio collared	Caribou were not found in areas of high snowmobile use over several years in mountain blocks. Habitat modeling indicated that significantly lower numbers of caribou were using snowmobile habitat than expected based on habitat quality.	Snowmobiling should be restricted from high-quality mountain caribou winter habitat, or at least limited to a small proportion of the total high-quality habitat for each herd.
Siemer et al. 2007: perspectives of residents in communities near Fire Island National Seashore	*Ov*	No	Fire Island National Seashore, NY	na	Survey	Residents closer to the park had more interest in deer issues. Mostly concerned with deer eating trash and disease.	Year-round residents and adjacent community members were more concerned about impacts from deer and more interested in providing input. Need to educate residents.
Singer 1978: Behavior of mountain goats in relation to U.S. highway	*Oa*	Yes	Glacier NP, MT; na	roads	Observational, n=117 days of observations	A total of 87 successful crossings (692 goats) and 31 unsuccessful attempts (101 goats) were observed in 1975.	Create an underpass so that goats can move to mineral lick without traffic.
Sorensen et al. 2008: Determining sustainable levels of cumulative effects for boreal caribou	*Rtt*	Yes	Alberta; 50,000 km^2	Oil and gas development, forestry	Comparative, n=6 caribou herds	Compared the cumulative amount of all industrial development and natural disturbance (fire) against caribou population growth rates (Lambda) in 6 different herds. Lambda well predicted by % industrial development.	5 of 6 caribou herds declining in study because industrial development exceeded thresholds of a maximum of about 40-60% of the range impacted by industrial development. Recommend planning at the range level (~8,000km2) scale.
Stankowich 2008: Ungulate flight responses to human disturbance	*ungu lates*	Yes	na	na	Review	Large amounts of heterogeneity between species and populations, generally humans on foot were perceived as most dangerous, ungulates can habituate to human activity, open habitats result in more flight.	Humans influence ungulates and are important in their flight response. Interactions may not be additive but interactive and multiplicative. Specific information is need on populations to ensure flight response is addressed.
Stewart et al. 2002: Temporospatial distributions of elk, mule deer, and cattle	*Ce, Oh*	Yes	northeast OR, southeast WA; 14.53 km^2	na	Observational, n = 14 cattle, 18 mule deer, 25 elk	Mule deer and elk selected for habitat but cattle did not, elk preferred mesic and logged forest, mule deer avoided xeric grassland, mesic forest. Mule deer and elk were more apt to use higher elevations and steeper slopes.	There is resource partitioning occurring between 3 species, competition as well. Acknowledge competition and get to know it better in site specific areas.
Thompson & Henderson 1998: Elk habituation as a credibility challenge for wildlife professionals	*Ce*	Yes	the West	na	Review	Hunting can stop habituation, risk of habituation is highest in winter, if human activity is constant (near development) it is feared less than sporadic (skiers and snowmobilers). Predation is limited near development; high population density causes dispersal toward development.	Keep elk populations down so dispersal doesn't occur, try to prevent habituation.
Varley 1998: Winter recreation and human disturbance on mountain goats	*Oa*	No	review	Human recreation and disturbance	Review	Conflict between goats and most recreation types are rare because of spatial segregation. Helicopters may pose a threat.	Helicopters should avoid areas within 2-2.5km of areas where goats are known to winter to avoid disturbance.

Table A-1 Cont.

Author: Short Title	***Spp***	**Peer Re-view**	**Study Area location and size**	**Development Type**	**Study Design**	**General Results**	**Conclusions & Management Recommendations**
Vistnes & Nellemann 2001: avoidance of cabins, roads and power lines by reindeer	*Rtt*	Yes	Norway; 213 km^2	resorts, power lines and roads	Observational, n= 776 and 678 caribou in each season	Reindeer density was 78% lower within 4km of a tourist resort complex and 73% lower within 4km from high voltage power lines. Forage availability also decreased significantly with increasing distance from human impacts.	Reindeer avoid human disturbance even at low levels of human traffic. Cumulative effects increase fragmentation and may reduce body condition and calf survival.
Vistnes & Nellemann 2008: a review of reindeer and caribou response to human development	*Rtt*	Yes	review	human activity	Review	Rangifer tarandus will reduce use of areas within 5 km of infrastructure and human activity by 50-95%.	Mitigation must regulate human impacts in caribou habitat.
Weclaw & Hudson 2004: simulation of conservation and management of woodland caribou	*Rtt*	Yes	Alberta; 20,000 km^2	roads, infrastructure	Modeling	The most detrimental factor is the loss of habitat due to avoidance of good habitat in proximity of industrial infrastructure.	Wolf control is not a practical solution. Development thresholds to maintain habitat required.
Yost & Wright 2001: Moose, caribou, and grizzly bear distribution in relation to road traffic	*Aa, Ua, Rtt*	Yes	Denali NP, AK; 130 km road	Roads	Observational, observed animals in backcountry and along roads	Moose sightings were lower than expected within 300 m of the road. more moose than expected occurred between 900 and 1200 m from the road.	The distribution of moose sightings suggests traffic avoidance, but the spatial pattern of preferred forage may have had more of an influence.

Notes: Abbreviations are NP, national park; NF, national forest.

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