2008

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Recommended Citation

Hebblewhite, Mark, "A Literature Review of the Effects of Energy Development on Ungulates: Implications for Central and Eastern Montana" (2008). *Wildlife Biology Faculty Publications*. 48.
https://scholarworks.umt.edu/wildbio_pubs/48

A Literature Review of the Effects of Energy Development on Ungulates: Implications for Central and Eastern Montana

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Acknowledgements

The author wishes to acknowledge Windy Davis, contract supervisor and energy-wildlife specialist for Montana Fish, Wildlife and Parks (MTFWP) for guidance and advice during this literature review, and Rick Dorvall, contracting officer for MTFWP for administering this literature review contract FWP # 080099. I also acknowledge the assistance of Darrin Newton, Zachary Voyles, and Jean Polfus for assistance in assembling the relevant scientific literature, and Kathryn Socie for editing the final version. I also thank colleagues Joel Berger, Kim Murray-Berger, Fiona Schmiegelow, Dave Naugle, Luigi Morgantini and Marco Musiani for ongoing discussions on the effects of energy development on wildlife in general.

Please cite as:

Hebblewhite, M. 2008. A literature review of the effects of energy development on ungulates: Implications for central and eastern Montana. Report prepared for Montana Fish, Wildlife and Parks, Miles City, MT.

Cover photos: M. Hebblewhite (elk, pronghorn, sheep, mule deer), J. Berger (pronghorn and energy development in the Jonah field).

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Executive Summary

A literature review of >160 scientific and technical reports was conducted to review the effects of energy development ungulates, separated by important seasonal and habitat types. Effects of energy development and human activity in general were assessed for elk, mule deer, pronghorn antelope, moose, bighorn sheep and woodland caribou. Weaknesses of the existing literature in addressing and providing guidelines for the management of energy development are presented. A recommended course of action for management oriented research is presented. Finally, a searchable electronic database is developed of the literature including abstracts and digital copies to aid in evaluating future energy development on ungulates.

The current management policy for energy development makes two untested assumptions regarding the effects of energy development on wildlife. First, it assumes that negative impacts of energy development on wildlife can be mitigated through small-scale stipulations that regulate the timing and duration of activity, but not the amount. This current policy also assumes that wildlife populations can withstand continued, incremental development. Neither of these two assumptions are supported or refuted by evidence reviewed in the scientific literature as part of this review. Regardless, adaptive experiments to explicitly test these management hypotheses are needed.

There is currently no rigorous scientific evidence that energy development will have population-level impacts on pronghorn, mule deer or elk in eastern or central Montana. However, this is because there have been no properly designed, thoughtful, rigorous tests of the population-level impacts conducted to date. Instead, a host of observational studies on small-scale and short-term responses provides limited guidance to managers in search of the crucial question of population impacts. While theoretically justified, relying on the precautionary principle to restrict energy development will likely be unsuccessful as an energy development policy.

Short-term and small-scale impacts of energy development have been relatively well described in previous reviews and studies, albeit most often in poorly designed observational studies. GPS collar studies have aided attempts to document small-scale responses to development, and will continue to be useful in the future in this correlational framework. Ungulates predictably avoid areas during active exploration and drilling, moving to denser cover and areas farther from human activity. Recommendations from previous studies still hold, namely timing and seasonal restrictions for critical habitats and resources. Across studies, ungulates showed avoidance responses to human development an average of 1000m from the human disturbance.

Scaling up from small-scale/short-term studies to population-level impacts will be difficult. One of the key difficulties is scaling up responses of ungulates at low development densities to high densities present in heavily developed oilfields (e.g. Upper Green River Basin). Preliminary analyses suggest that thresholds for significant impacts on ungulates will occur between densities of 0.1 to 0.5 wells/km^2 and 0.2 to 1.0 linear km/km^2 of roads and linear developments. However, these results are preliminary, and more formal meta-analyses are suggested.

Building on the strong example of the Montana Cooperative Elk-Logging study that ran through the 1970's and 1980's, a series of research and management recommendations are made. First, a formal meta-analyses of the existing energy literature is recommended to allow scientifically defensible quantitative estimates of the effects of energy development on behavior, habitat and population dynamics.

Second, building on this meta-analysis, a power analysis of the optimal experimental design, level of replication, and duration of a energy-impact study design should be conducted to reveal the best approach for both short-term (behavior, habitat) and long-term impact assessment.

Third, a series of large-scale, population-level and long-term experimental comparisons similar to the Montana Cooperative Elk-Logging study should be initiated in eastern and central Montana on elk, mule deer and pronghorn. The study design should be replicated ideally across three levels of development; none – control, initial phases – low densities of wells/roads, and after at least a decade of intensive development, to allow a rigorous test of the population effects of energy development on wildlife. Partnerships with existing studies occurring in other developed areas should be developed (e.g., Upper Green River Basin studies), but control areas in Montana should be developed (e.g., Charles M. Russell Wildlife Refuge).

Fourth, implement an adaptive management experiment (in conjunction with the third point above) to test whether the current energy policy is sustainable from a wildlife population perspective. The de-facto energy policy being implemented in Montana (and elsewhere) makes a number of assumptions that may in fact be incorrect. However, no valid alternatives have been developed or put forward as serious contenders that could be compared in large management experiments to test whether different models for energy development are required. If the bleak situation for Alberta caribou is any suggestion, alternative energy development policies are sorely needed.

1.0 INTRODUCTION

Increased energy consumption and the perception of over-reliance of the United States on foreign oil deposits to meet domestic energy requirements lead to a national level policy to: increase energy efficiency, develop new energy resources, improve efficiency and extraction of energy from existing resources, and improve the efficiency of key international energy consumers (American Gas Association 2005). This national policy manifested in Montana in October of 2005 when Governor Brian Schweitzer revealed the Schweitzer Energy Policy (Governors Office of Economic Development 2005). This Montana Energy Policy emphasized the following energy development themes in Montana, calling for diversification, a commitment to renewable and cleaner development (including clean coal), increased energy efficiency and conservation, increasing supportive infrastructure and adherence to environmental laws and community acceptance. Within the Department of Commerce, the Division of Energy Infrastructure, Promotion and Development's (DEIPD) mission statement is to:

> *"The Division's mission centers around promoting and developing additional energy distribution capacity so that potential jobs become actual jobs and Montana's tax base is further enhanced for the benefit of its citizens. Increased distribution capacity also paves the way for clean, green energy creation and utilization. We will work to facilitate the promotion and development of energy infrastructure that will allow the responsible development of Montana's abundant energy resources including wind, bio-fuels, geothermal, biomass and clean coal gasification, liquefaction and power production which use carbon sequestration technologies when possible." (DEIPD, Dept.of Commerce, Government of Montana, 2008)*

The effects of this government policy on energy development have been felt strongly in the energy sector. In Montana since 2005 oil production has increased 50% and a state renewable energy portfolio tax and incentive program to increase the growth and production of renewable energy was adapted. The state has increased tax incentives for energy development, earning itself recognition as one of the most favorable and lowest taxed places to develop energy in the world (Business Facilities Magazine 2007); initiated the Montana Alberta Tie electrical energy transmission project, and developed proposals to increase both renewable and non-renewable energy resources throughout eastern and central Montana in conjunction with federal land management agencies such as the Bureau of Land Management (BLM). Between 2002 and 2006, oil production has increased 213% (barrels production), the number of oil wells 17%, and the number of natural gas wells 34% while production increased by 17% (Montana Board of Oil and Gas Conservation 2006). While this relative growth is impressive, comparison to the heavily developed oil and gas fields of Alberta (40% larger in area to Montana) reveals Montana production is <10% of currently active oil and gas wells in Alberta, which is also undergoing similar rates of growth (10-20%, Alberta Energy 2008). Thus, from an energy development perspective, Montana is just getting started.

This increase in development in Montana closely matches the nearly 60% increase in the number of permit applications throughout the Rocky Mountain West in the last decade (American Gas Association 2005), with much of it focused on Montana, Wyoming and Colorado. Montana is touted as having amongst the greatest undeveloped natural gas and oil fields in the country (American Gas Association 2005), much of it in the Montana Thrust Belt (north-east Montana), Powder River basin (south-central Montana), and East Front deposits. Despite the focus on renewable energy development by Montana's Schweitzer Energy Policy, however, federal-state policies will ensure that traditional, non-renewable energy development will constitute the bulk of the growth in energy development in Montana, especially in these key energy deposits.

For example, within the Powder River Basin region (~16,000 km^2) within the state of Montana (BLM 2003a, b), as many as 18,000 coal bed natural gas (CBNG) wells have been approved for drilling on federal lands by the Bureau of Land Management (BLM, 2003a, b). This massive increase in oil and gas development will be associated with similar increases in infrastructure and development. For example, each CBNG wellsite is accompanied by construction of 2-7 km of access roads and 7-22 km of power lines per km^2, as well as compressor stations, pipelines, holding ponds, etc. (Bureau of Land Management 2003a, b). Other types of energy development, such as traditional oilfield drilling, natural gas development, coal bed methane, and new renewable energy developments such as wind power are also associated with extensive road, power line and pipeline developments. Throughout Montana, similar resource management plans focusing on energy development have been developed by the BLM, a key federal regulating agency on federal lands, ensuring the future expansion of energy development in eastern and central Montana, especially the Billings, Big Dry, Headwaters, Powder River Basin, and Judith Valley Phillips resource management planning areas administered by the BLM (BLM 2008, see Fig. 3 below).

Increased energy development, and the infrastructure associated with well sites, has the potential to have profound impacts on natural ecosystems in eastern and central Montana. Given this backdrop on intensive energy development, the Montana Department of Fish, Wildlife and Parks faces a huge policy, administrative and technical challenge to meet its goals to:

> *"Sustain our diverse fish, wildlife and parks resources and the quality recreational opportunities that are essential to a high quality of life for Montanans and our guests (MTFWP, 2008)."*

Energy development has been shown to impact almost all natural resources including surface and subsurface hydrological processes, natural disturbance regimes such as fire, wildlife habitat, soil erosion processes, and wildlife population dynamics themselves (e.g., BLM 2003 a,b; (Naugle et al. 2004, Bayne et al. 2005)). While regulatory processes are in place that can provide some effective mitigation for key wildlife species, such as the potentially threatened Greater Sage Grouse (*Centrocercus urophasianus*) (Aldridge and Brigham 2002, Naugle et al. 2004), mitigation strategies are usually implemented on a site-by-site basis at the scale of the individual well site, or at intermediate scales across several wellsites or adjacent oil fields. Regardless, with petitioning, even small-scale mitigation at the site of the individual wellsite can also be waived by federal agencies. And the situation is even less regulated on private lands, where a substantial portion of energy development is occurring; few to no guidelines exist to minimize the impacts of energy development to wildlife. Regardless of the small-scale regulations often applied to individual well site permits, the impacts of energy development on wildlife especially are most often felt through cumulative effects of not just one wellsite at a time, but across large landscape scales in the order of 1000's km^2 (Kennedy 2000, Schneider et al. 2003, Aldridge et al. 2004, Johnson et al. 2005, Frair et al. 2007, Walker et al. 2007). Thus, MTFWP faces the difficult task of sustaining populations of wildlife at large landscape scales across Montana despite the regulatory and policy challenge of relatively small scale and piecemeal environmental impact assessment.

To aid the mission of MTFWP, a series of reviews of the effects of energy development on key wildlife species was initiated in 2007. This review constitutes part of this process and focuses on reviewing the effects of energy development on ungulates throughout the Rocky Mountain western with particular attention towards habitats in eastern and central Montana including sagebrush, grassland and pine-breaks habitats. The following ungulate species are considered the focus of this review, bighorn sheep (*Ovis canadensis*), American pronghorn (*Antilocapra antilocapra*), elk (*Cervus elaphus*) and mule deer (*Odocoileus hemionus*), although effects of energy development on the large mammal community in which these key ungulate species reside will also be considered. Moreover, given the extensive literature on the effects of energy development on woodland caribou (*Rangifer tarandus*), particularly in Alberta, I review the impacts of energy development there with a focus on providing key insights to Montana in terms of developing effective mitigation and cumulative effects assessment strategies. Given the vast difference between both the means of energy development and wildlife present in the arctic (e.g., National Research Council 2003), I do not review the effects of energy development on arctic ungulates, but discuss where appropriate. The objectives of this literature review are:

1) Review the effects of energy development (including oil, gas, and wind development) on ungulates, separated by important seasonal and habitat types.
2) Review the weaknesses of the existing literature in addressing and providing guidelines for the management of energy development.
3) Provide a conceptual framework for understanding the effects of energy development on ungulates
4) Recommend a course of action for management oriented research on the effects of energy development on ungulates.

5) Develop a searchable electronic database of the literature including abstracts and research summaries, where possible, that will be useful in evaluating future energy development on ungulates.

2.0 LITERATURE REVIEW METHODS AND SCOPE

Recent comparisons of literature reviews in ecology vs. those in the medical field revealed that ecological literature reviews often lack details of the methods used to search for studies, thus increasing potential bias in literature reviews, and made fewer efforts to review unpublished literature (potentially showing no effect because of the bias against negative results). Ecological reviews were also less likely to assess the relevance of the study in terms of quality of experimental design and made fewer efforts to quantitatively synthesize results using methods like meta-analyses (Roberts et al. 2006).

I follow the recommendations of Roberts et al. (2006) herein, by describing the methods used to conduct the literature review on the effects of energy development on bighorn sheep, elk, mule deer and pronghorn (as well as woodland caribou). I also assess rigor of study design following methods described below.

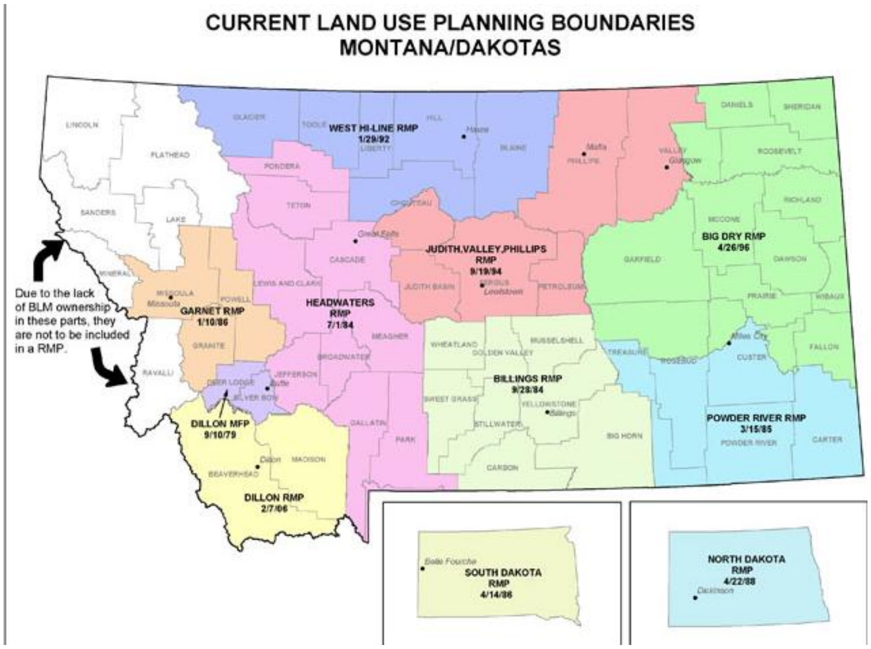


Fig. 1. Study area for the literature review of the effects of energy development on ungulates, BLM (2003a,b). This review focuses on areas in the Powder River Resource Management planning (RMP) area, the Big Dry RMP, the Judith Valley/Phillips RMP, the West-Hi Line RMP, Billings RMP, Headwaters RMP, and Garnet and Dillon RMP's.

2.1 Literature Review

I conducted a literature search of energy-ungulate impact studies using a variety of electronic, on-line databases, personal communications, and management reports from the period from 1970 to the present. Databases included: ISI web of science, Google scholar, Absearch, BIOABSTRACTS, Biological Abstracts, Environmental Sciences, Dissertation Abstracts, Government resources, Geology abstracts and Forestry abstracts. I searched databases using combinations of the following keywords: bighorn sheep, elk, mule deer, pronghorn, energy development, petroleum development, oil development, gas development, wildlife, ungulate, and the western states (e.g., Wyoming, Montana, Idaho, Colorado, Utah) as well as Alberta and British Columbia. From this list of potential scientific literature, I screened studies to include at least one large ungulate species preferably within the same types of habitats as present in eastern and central Montana. I focused on studies applicable to the BLM resource management planning areas identified in Fig. 3. See appendix A for a summary of the types of literature reviewed.

To facilitate synthesis and review, from each study, I recorded information in the following categories: study area; methods, results, recommendations and implications. For each category I recorded the following variables:

Study area

- focal species, sex- and age-classes investigated
- study area size, location, and duration of study
- seasonal information (winter or summer range impacts),
- vegetation communities (sage steppe, grassland, mixed, pine breaks, forests – foothills and mountain)

Methods & Experimental Design

- type of development (oil wells, gas wells, coal bed methane, coal bed natural gas, wind power, coal, other)
- density of human developments (units/km^2)
- study design type (in increasing order of rigor starting with observational, correlative, comparative, experimental, pre- and post- data, before after control impact design (Underwood1997,Krebs1989)) and degree of replication (if any);
- field methods (e.g., observational, aerial survey, pellet surveys, snow track surveys, telemetry)
- response variables (e.g., group size, vigilance, habitat selection, population demography), and

- statistical methods

Results
- general results
- effect size(s) (see meta-analysis section below),
- sample size, and
- measures of variation in the effect size;

Conclusions
- imitations, both identified by the authors, and this review
- management recommendations
- conclusions of each study

I revisit concepts of experimental design in the discussion with recommendations for future adaptive management experiments about energy impacts on wildlife in Montana.

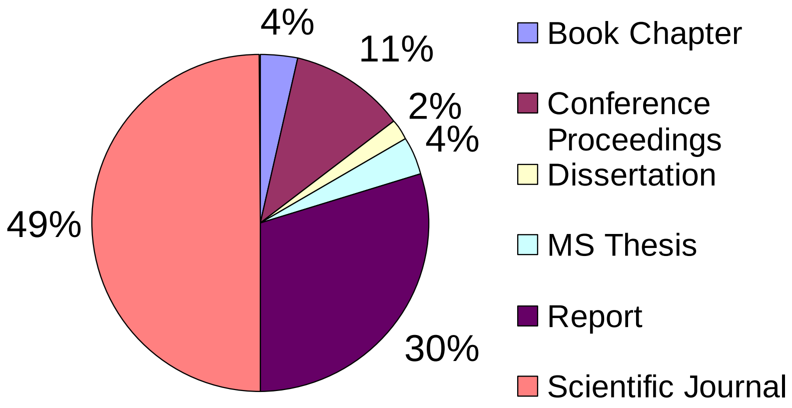
Furthermore, because of the importance of roads, and the avoidance of them by ungulates in the literature (Lyon 1983, Rowland et al. 2004,Frair et al. 2007,Edge and Marcum 1985,McCorquodale et al. 2003,Rost and Bailey 1979), I report the mean distance or distance classes avoided by ungulate species in each study for observational and experimental studies. The effects of roads in general are a huge subject and have been the target of dozens of ecological reviews (Forman and Alexander 1998,Trombulak and Frissell 2000), which similarly classify impacts of roads as direct (mortality) or indirect (avoidance). Moreover, human recreation associated with roads is a huge management topic with many excellent reviews even in Montana (Joslin and Youman 1999), so I do not attempt to review this literature. In this review, I only focus on synthesizing quantitative studies about the distance at which ungulates avoided roads in habitats similar to eastern Montana. Broad recreational and road impacts are discussed, but only in the context of potential impacts of energy development.

3.0 RESULTS

3.1 Literature Review Summary

3.1.1 Species and publication type

I found 120 publications that met the search criteria and that I was able to locate for this review. However, not all of the literature was species specific or relevant to energy development, and are included in the literature database only for background reading. For example, studies of the cumulative effects of energy development on caribou in Alberta are included (Schneider et al. 2003), but not reviewed in detail here because the focus was on studies on the four main ungulate species. Literature reviews themselves were also not included in the literature review, often because we were reviewing the same limited literature, ironically. Finally, modeling or theoretical studies, while useful in the context of interpreting the results of field studies, were not included in the literature review of field studies that documented the effects of energy development on wildlife. Thus, of the 120 or so studies assembled, 70 were direct field studies that investigated aspects of energy



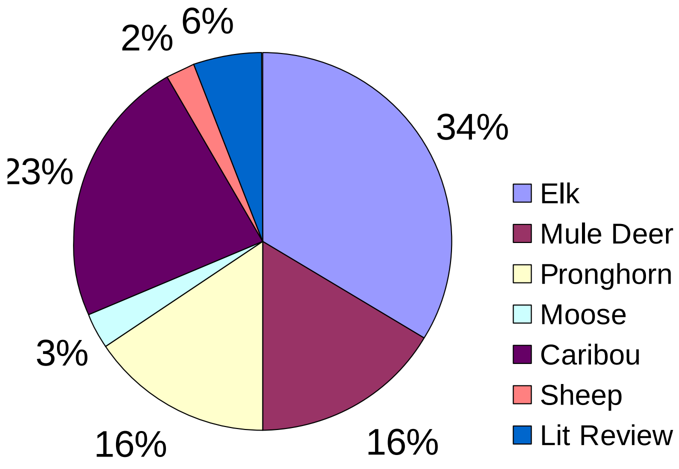


Fig. 2 & 3. Proportion of the studies that directly studied aspects of energy development on wildlife (n=70) by 2) publication type and 3) species, including literature reviews as a category.

development or more broadly human development or disturbance, on wildlife in habitats relevant to eastern Montana.

Of the 70 studies, almost 50% were peer reviewed scientific publications in the primary literature (Fig. 2). The second largest category were reports, 30% of all literature reviewed. Conference proceedings, specifically the Thorpe conference series prominent in the 1980's, constituted 11% of all literature, and a combination of book chapters, and graduate theses (MS, PhD) made up the rest of the sample. Considering graduate theses as peer reviewed, but conference proceedings, book chapters and reports as not, 53% of all literature was peer reviewed. While other authors consider graduate theses as unpublished, I disagree with this view, especially in contrast to management reports that undergo variable and undocumented peer review during the design, implementation, and analysis of the impacts of energy development. Peer review within a University department for a graduate thesis greatly exceeds the level of peer review for reports.

Elk were the most common ungulate in the literature reviewed the subject of study in 45 studies. Woodland caribou were the subject of 29 studies. Mule deer and pronghorn had a similar number of studies, 20 and 21, respectively, followed by Moose (4) and Bighorn Sheep (3). On average, each study examined the responses of 1.4 species to energy development (Table 1), with the most common ungulate combinations being mule deer and pronghorn, or mule deer, pronghorn and elk. A surprising number of literature reviews have been conducted on this scanty literature, and these constituted ~12% of all studies considered here.

3.1.2 Study design, methods, sample size

From a study design perspective, most studies (n=27, 47%) used a weak observational approach where the impacts of the development were inferred from correlations between human use activity levels and measures of ungulate responses to treatments. I defined comparative studies as those that compared ungulate responses to development by comparing effects before and after development, but without a suitable control, obviously a weaker design than with a control. Comparative designs were used in 19% (n=11) of the studies. I defined experimental designs where effects were compared between an impacted and control group at the same time, so that the control was contemporaneous. However, in this design, effects of development before and after development are not discernable. To tease apart impacts before and after an energy development, only 10 studies (18%) used the most powerful experimental design, a before-after-control impact design (Underwood1997,Krebs1989). Half of both the comparative and experimental studies utilized a before-during-after study design, where the effects of the energy development phase was contrasted with both pre- and post- data. This was the most powerful design for determining the short term impacts of development on ungulates. **No studies were replicated at the level of impact type: all studies used only 1 replicate.** I return to the issue of experimental design in the discussion with recommendations for MTFWP.

A review of the most common methods used to evaluate the impacts of energy show a higher frequency of telemetry studies compared to other methods; 51% of all studies were conducted using radio telemetry, and most of these (95%) were with conventional VHF telemetry, GPS collars the other 5%. Approximately 51% of all studies used radio telemetry, collaring a total of 1537 animals throughout their duration, the most common of which were elk (48%), followed by pronghorn (26%), mule deer (18%), and lastly, caribou (4%). There were no published studies of moose or bighorn sheep responses to energy development using radiotelemetry. The most common alternate methods to assess effects of humans on ungulates were aerial surveys (15%) and pellet or sign/track surveys (20%).

The average sample size (n) used in energy-wildlife studies was 57.5, the median 39.5, and this did not differ much from the sample size of only telemetry studies, where sample size in

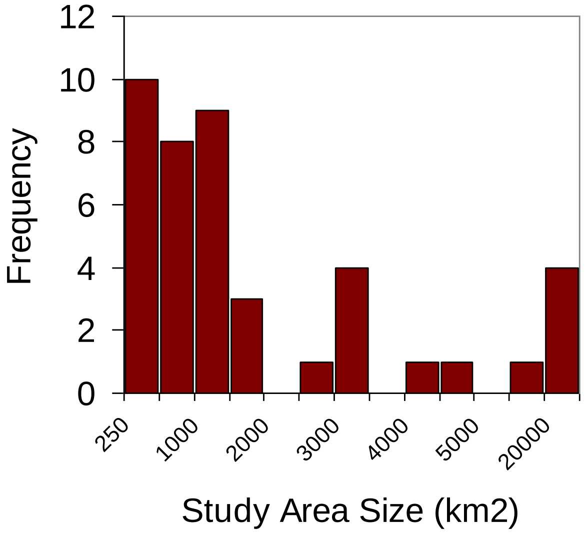


Fig. 4. Frequency distribution of study area sizes for studies on the effects of energy development on ungulates (n=44).

this case correctly represents the individual animal sample unit (Gillies et al. 2006,Otis and White 1999), not the number of sub-sample telemetry locations. However, considering the number of telemetry locations per individual animal, these were often quite low for VHF collared animals, with an average of only 22 VHF telemetry locations obtained per animal per study; for seasonal (winter, calving, summer) this sample size is even smaller. Across all studies, over 2000 ungulates were radiocollared to evaluate impacts of energy development, with mortality rates that ranged between 0% and 15% (mean 4% reported from n=10 studies, or approximately 80 mortalities).

Psuedoreplication (Hurlbert 1984) was a common problem in all studies. Approximately 30% of all studies committed psuedoreplication where enough data was presented (i.e., clear experimental design, sample sizes, etc.) were sullied somehow with pseudoreplication issues. Common pseudo replication occurred when authors confused the number of telemetry locations with the true sample unit, the individual animal. Other common instances of pseudoreplication were with pellet surveys or track count surveys.

Oddly, studies often failed to report the study area size, a key parameter in ecological studies– for example, study area size influences ungulate densities, spatial scale, and the density of disturbance. In the discussion I review this critical problem of scale. Where study area size was reported (n=56), study area size ranged from 26km^2 to 190,000 km^2. Studies of boreal woodland caribou populations were the largest, averaging 28,000 km^2 (range 225 – 190,000km^2), and were statistically larger than all other ungulate species study areas (ANOVA P-value <0.01). Not including caribou, the largest study area size in the lower 48 was 15,000km^2 in Wyoming (Sawyer et al. 2005b), and there were no differences amongst species (ANOVA, P>0.3). However, mean study area size was strongly left-skewed; while the mean study area size appears large, 3382km^2, the median was significantly smaller, only 798km^2, shown in Fig 4. This area is equivalent to a 15km^2 radius circle.

Table 1. Summary statistics for literature on the effects of energy development and human disturbance on ungulates, n= 126 studies.

Metric	Mean	Median	Range	StDev
Sample size	57.5	39.5	4-223	53.6

No. of collared animals in telemetry studies	58.7	34.2	4-223	60
Number of telemetry locations/animal	22	17	1-55	??
Population size	3950	1000	35-48000	22058
Study area size	3882 km^2	798	26-20000	5924
Study duration	2.7 years	2.1	0.15 - 11	2.28

The population size of inference for ungulates affected by energy development in the studies reviewed averaged 3950 animals, again, with a left-skewed distribution resulting in a much lower median of 1000 animals. The range of population sizes of ungulates impacted ranged from 35 to 48000, for mule deer in the Upper Green River valley of Wyoming (Sawyer et al. 2005b,Sawyer et al. 2002). From a sampling perspective, then, the average telemetry-based study sampled a mean of 1.5% of the population present, or a median of 4% of the study population of inference.

Study duration was also summarized across studies. Almost all studies were of extremely short, most often for the duration of active drilling activities, exploration, or mining development. Mean study duration was 2.6 years, and median duration 2.2 years. The range was basically 2 months to 11 years. The longest running study, consisting of annual aerial surveys by (Hayden-Wing 1990), ran from 1979 to 1990 in the Riley Ridge area of Western Wyoming: the study is no longer running. The earliest study reviewed occurred in 1969, when (Bruns 1977) conducted an observational study on pronghorn in SE

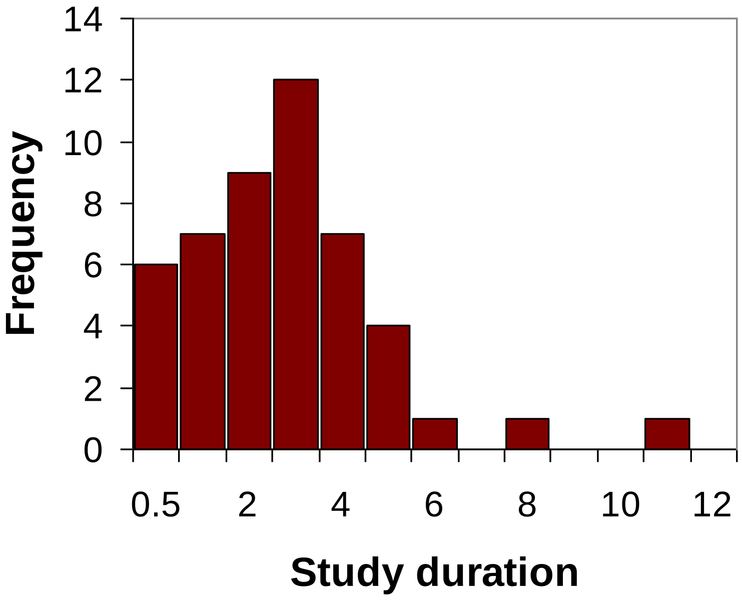


Fig. 5. Frequency distribution of study area duration for studies on the effects of energy development on ungulates where duration was reported (n=56).

Alberta. Altmann's (1958) classic study was not strictly on the effects of energy development on ungulates. The majority of studies were conducted in two peaks, the second of which we are in now, and the first, during the 1980's (Fig. 5). These two peaks in studies correspond closely with the peaks in energy exploration and development in the last three decades (American Gas Association 2005, Oil and Gas Conservation Division 2006).

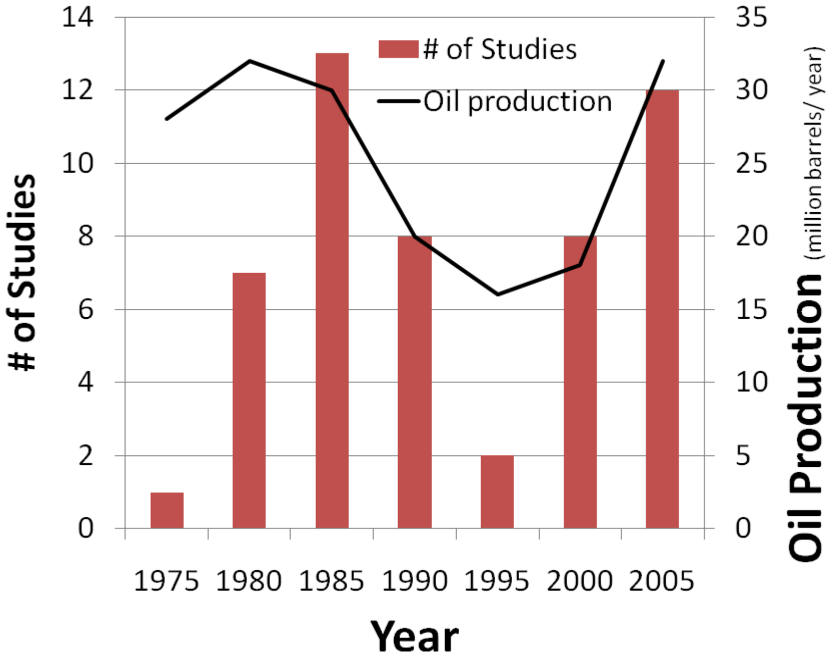


Fig. 6. Frequency distribution of study date for studies (n=60) on the effects of energy development on ungulates plotted against peak oil production in Montana (in millions of barrels of oil/year; source Oil and Gas Conservation Division (2006).

3.1.3 Types of Energy Development

Of the types of energy development studied, by far the most frequently studied activity was the effects of active seismic exploration or well drilling on an ungulate species (n=25, 31%). The next most frequent studies examined the effects of roads associated with oil and gas or forestry development on wildlife, followed by oil or natural gas well impacts on ungulates. There was an even mix of studies that investigated the effects of human activity in general, mining, logging, and military overflights on ungulates. There were 4 studies specifically designed to be pre-development studies, or in areas specifically at the beginning of energy development (e.g., Sawyer et al. 2002, Amstrup 1978, Ihsle 1981), but either development has not occurred, or no follow up studies have been conducted yet (to the best of my knowledge).

Moreover, careful reading revealed that of just the studies designed to investigate effects of energy development activities (n=56, nearly 70%) were reactionary and designed largely as consultancies to monitor and mitigate the environmental concerns of the development as a condition of the drilling or exploration permit (e.g., van Dyke and Klein 1996, Irwin 1984, Johnson 1980, Johnson 1987,Morgantini 1885, Horesji 1979). The remainders of the studies were designed to investigate the impacts of development on ungulates after the fact on an ad-hoc manner. **There was not a single case of energy development and management-oriented research proceeding in an adaptive framework in a manner to directly feedback into management of energy development (see discussion).**

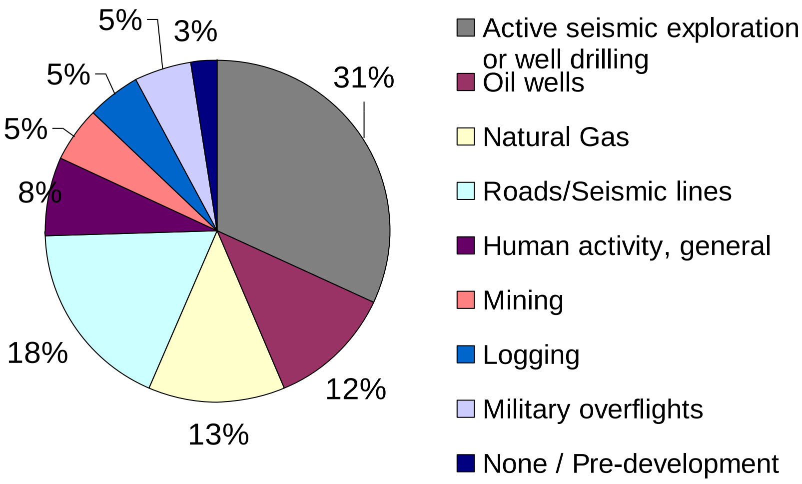


Fig. 6. Types of human disturbance and energy development studies that investigated impacts on ungulates (n=49).

Finally, from a vegetation community perspective, most studies were conducted in shrub-steppe vegetation communities and ecosystems (n=21, Fig. 7), followed by mountains (15), grasslands (11), and then pine breaks (e.g., Douglas Fir), boreal forest (caribou), foothills forests (e.g., Alberta), and other habitats such as present in Michigan.

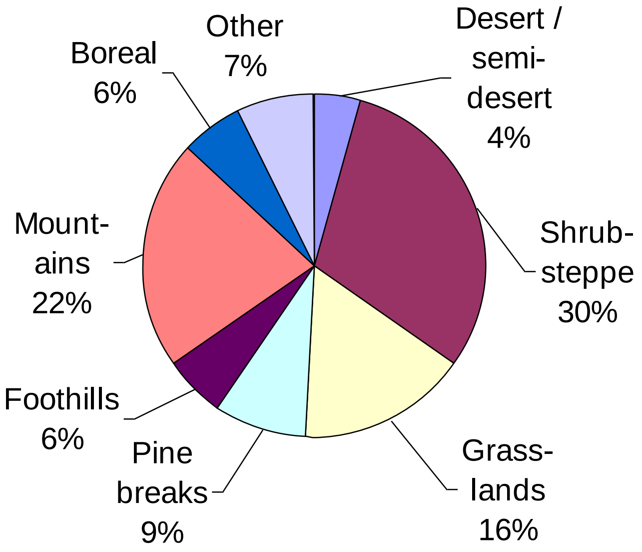


Fig. 7. Vegetation communities in which studies on the impacts of energy development on ungulates were conducted (n=69).

3.2 Elk *(Cervus elaphus)*

I now summarize, by species, the results of individual studies reviewed, commenting on their location, species, study designs, methods, and general conclusions and especially, limitations. Results by species are then summarized in a table at the end of each of the main species reviewed in this review.

3.2.1 Sagebrush Steppe and Grasslands

In perhaps the longest conducted surveys of ungulate response to natural gas field development (Hayden-Wing 1990) summarized results of 11 years of aerial survey monitoring of elk populations on two elk ranges in southwestern Wyoming (Snider Basin and Graphite Hollow) that were developed for oil/gas wells. Vegetation types included sage-steppe, grassland, pine breaks and mixed communities. They surveyed elk annually on winter range and spring calving ranges pre construction, during, and afterwards, with no control sites for comparison. Elk avoided areas during the construction phase on both the winter and calving ranges, but reoccupied these areas after intense construction ended, although variation in the degree of avoidance was high over time. Also in the Snider basin area of Wyoming, in 1978-80, (Johnson 1980) conducted an observational study of the effects of natural gas well development on elk using photo cameras, pellet surveys, and aerial and ground surveys. Elk were affected by activity on the access road, avoiding the area; cows moved calves at earlier age; elk were displaced away from drilling rig in 1979. However, a lack of pre-drilling data hampered interpretation, and the study was reactively designed in response to development.

Similarly, elk avoided roads, active gas and oil wellsites the most during summer months in the sage-steppe ecosystem of the Jack Marrow Hills, WY (Powell 2003), strongly selecting habitats greater than 2000m from these features. Avoidance of roads and wellsites declined in the fall, winter and spring when elk only avoided areas <500m surrounding human development. During calving (15 May – 30 June), elk avoided areas <1000m from roads and wellsites. This study was observational, and only examined responses of elk following development, but makes the important observation that elk continued to show avoidance of wellsites long after the construction phase had been completed.

In Colorado, (Johnson 1986) conducted an experimental (n=1 replicates) study of the effects of coal mine development on elk over a 5-year period from 1981-1984. Vegetation types were a mix of sage steppe, grassland, shrub, aspen and conifer. Johnson (1986) compared calving home ranges, site fidelity, habitat use/selection, noise tolerance and cow/calf ratios between a treatment mining area and control areas within 20 miles of the mining development, and reported no statistical differences between any variables, and concluded that coal mine development did not influence elk. However, there was some evidence that elk near the coal mine displayed lower fidelity (5796m between successive home range centroids between years) than control elk (3723m). These results are consistent with displacement by the coal mine. Potential limitations of the study are confounding between the putative control and treatment locations which were close together and between which radiocollared elk mixed throughout the study (Johnson 1986). Regardless of these problems, elk selected reclaimed coal mine sites in proportion to their availability in the landscape, neither selecting nor avoiding reclaimed areas, emphasizing the importance of reclamation activities.

Ward (1986) conducted another observational, non-experimental, study on the effects of seismic exploration on elk in the known recoverable coal resource area of south central Wyoming over 4 years from 1981-84. Vegetation types were sagebrush steppe and grasslands. Ward (1986) used ground telemetry from an unreported number of elk with an unreported number of telemetry locations combined with an unreported number of ground and aerial surveys to examine the distance of elk to development. Ward (1986) also measured sound levels (dbA) at various distances from seismograph equipment. Elk were affected most by foot traffic; distance of elk displacement depended on line-of-sight of the elk to the disturbance. In places with no topological barriers, elk displaced about 3.2 km, but where terrain yielded topological barriers, elk displaced 800 m. Following the cessation of seismic exploration, elk returned to areas of disturbance a few days after activity was concluded. Ward (1986) concluded that elk in this study did not seem to be affected detrimentally. However, where winter range habitat is limited, these disturbances have the potential to have major effects on elk. Limitations of this study are obvious; the number of collared elk, details of aerial or ground surveys, and statistical tests were all absent.

Hiatt (1981) conducted an observational study of the effects of drilling a single well on Crooks Mountain in Wyoming during late winter 1981 in response to concerns over drilling effects on ungulates in winter range. Hiatt (1981) used track counts, ground and aerial surveys and time-lapse camera's to quantify the response of elk and mule deer to development. The study was putatively a before-after comparative study, but was critically limited by only 9-days pre-development monitoring – the report gives the impression that this was an extremely reactionary study conducted at the 11th hour to ensure something was done to address environmental concerns. Hiatt (1982) concluded that both elk and mule deer shifted their ranges away from the well site, and that there was no evidence of avoidance of the access road by either species. Limitations of this study are obviously the scanty pre-treatment data, lack of control, and lack of replication. Remote cameras were of limited utility, collecting few observations and being limited by the small number of cameras deployed. Moreover, statistical analyses were psuedoreplicated at the level of the individual track-count, which were collected along transects – the true sample unit. Therefore, it is unclear whether the conclusions from this study are warranted, although it is consistent with previous literature that shows a decline in ungulate use during drilling operations.

Van Dyke and Klein (1996) also studied the effect of active drilling operations on elk in the grassland and shrub-steppe communities near Line Creek Plateau in Montana by comparing seasonal an annual home range characteristics and use of cover for 10 VHF collared elk from which they obtained 474 telemetry locations over the period from 1988 to 1991. They assumed this represented the population of 120 elk that used the entire study area. Van Dyke and Klein (1996) compared home range size, home range centroid, and coarse grain habitat use by elk before, during, and after development, each phase lasting 1 year. Elk in both the study site and the control site had significantly different distributions within the ranges, suggesting a normal seasonal change rather that effects of drilling. In terms of resource selection, elk at the study site were rarely found outside of forested areas during the day while activity was taking place at the well sites. Elk responded to disturbances by shifting their use of the range, centers of activity, and use of habitat. Elk maintained a physical barrier between themselves and the well site during active drilling, and the authors concluded that elk do not abandon their home ranges during well site development, and quickly return to pre-development conditions following development.

Unfortunately, limitations of this study are many; 1) small sample sizes per elk to accurately estimate seasonal and annual home ranges – with only 474 locations/10 elk/ 2 seasons (winter/summer) over the ~4 years of the study yields approximately 6 locations, naively, per elk per season-year – woefully low for reliable home range and centroid estimation (Powell 2000); 2) scale – this study evaluated the effect of a single oil well in an approximately 500km^2 area (note study area size was not presented, but is estimated from figures in the paper), a density of 0.003 wells/km^2, a trivially low density for such a huge area!; 3) the choice of large-scale home range analysis methods to evaluate the results of a single small-scale concentrated development also limits the strength of inference. The utility of this study to current oilfield development, where multiple, often dozens of simultaneous wells are being drilled in an existing matrix of developed oil fields is questionable, and future studies should pay particular attention to this issue of scale.

In a recent and well designed observational telemetry study of elk resource selection in a grassland/shrub-steppe ecosystem in southwestern Wyoming, Sawyer et al. (2007) examined the response of elk in open habitats to distances to roads. This study system is important because while the area has low densities of oil and gas development at present, this region is considered to have moderate to high oil and gas development potential (see Sawyer et al. 2007). Thus, this study represents a well designed pre-treatment study if development proceeds in the future, and is a valuable insight into elk resource selection in shrub-steppe ecosystems under relatively low development. Sawyer et al. (2007) developed resource selection function (RSF, Boyce and McDonald 1999, Manly et al. 2002,Boyce 2006) using telemetry locations from 33 GPS collared female elk during both winter and summer. Models were validated against 55 VHF collared elk telemetry locations. Elk selected for summer habitats with higher elevations in areas of high vegetative diversity, close to shrub cover, northerly aspects, moderate slopes, and away from roads. These results were generally consistent with the results of McCorquodale et al. (1986) in the shrub steppe of eastern Washington. Winter habitat selection patterns were similar, except elk shifted to areas closer to roads than in summer, indicating a strong response of road avoidance during summer. Results suggest that large (1,000) hunted elk populations can meet their year round forage and cover requirements in nonforested regions with low traffic, a range of elevations and shrub communities. They conclude that management of roads and related human disturbance is an important consideration for managing elk populations, especially in open habitats.

3.2.2 Mixed communities

In the mixedwood forests of Upper Peninsula of Michigan, (Knight 1981) studied the effects of initial seismic exploration and oil well development on reintroduced elk before and during development using radiotelemetry. This was the initial phase of oil well development and the study had very little previous energy development. Elk of all ages and sexes moved significantly greater distances in the presence of seismic exploration than when no disturbance was present; i.e. there was a significant negative correlation between distance to disturbance and mean daily movements of elk. Terrain and vegetation type was not a significant factor in elk movements. There was no significant difference in elk home ranges with/without seismic disturbance. Once wellsites were installed, there was no correlation found between distance to disturbance and mean daily movements. Elk appeared to become habituated to the stationary well sites, but not to the unpredictable seismic exploration activities. Knight (1981) concluded that seismic activity significantly affects the movements but not the distribution of elk; oil well activity does not significantly affect the movements nor the distribution of elk.

The effect of hydrocarbon development on elk and other wildlife in Northern Lower Michigan was further studied by Bennington et al. (1981) for 1 year from 1979 to 1980 using aerial surveys and ground track surveys. Wellsite densities were among the higher reported in the literature, approximately 0.22/km^2 (exception being Frair et al. 2005), and most wells were active and in production. Despite a regional increasing population "trend" over previous 5 years, the subregional trend was a short-term decrease in elk activity following oil drilling, as revealed by significantly lower number of tracks at drilling vs. nondrilling sites. At each wellsite, Bennington et al. (1981) found temporary (2-4 wk.) relocation after development. Overall, Bennington et al. (1981) concluded there was no significant difference between pre-drilling and post-drilling activity at the given well density has only short-term relocation effects. Limitations of the study are potential pseudoreplication in the number of sub-transects analyzed at each site (the correct sample unit), and that the intensity and coverage of the ground and aerial methods varied from previous Michigan government surveys. Moreover, the study was an observational-correlational study, with no replication, control, or comparative design.

3.2.3 Mountains and Foothills

In the Bridger Teton National Forest in 1983, Irwin (1984) examined the preliminary effects of seismic exploration on 18 collared elk. Seven of 18 elk were displaced from their spring range after seismic activity was conducted. The elk did not return during the activity, but instead migrated to the summer range. Four other elk stayed on the spring range, but maintained a 1-2 ridge barrier between them and the disturbance. Limitations of this study were lack of comprehensive pre-data, and unclear statistical analyses.

In a follow up study in the Bridger-Teton National Forest during summers of 1983-1985, Gillin (1989) studied the effects of multiple seismic exploration events on 21 radiocollared adult female elk in control and treatment groups. Over the spring and summer period, Gillin (1989) collected an average of 134 locations/events from 9 collared elk in the control group, and 184 locations from 10 elk in the treatment group. Elk avoided active exploration on average by 1.2km in spring and summer. They also changed their habitat selection to select closed conifers 18% more and higher slopes 70% more (away from low elevation seismic) during seismic exploration than the control period. The author concluded that elk avoid seismic exploration, but do not shift their home range during exploration, but merely redistribute use within their home range.

The impacts of seismic exploration on elk were also investigated in the Badger Creek – South Fork of Two Medicine River of north central Montana during spring, summer and fall of 1981 by Olson (1981). Olson used a limited experimental design with small numbers of animals, comparing the effects of seismic exploration on 4 collared female elk against 2 collared elk in a 'control' area. Response variables were movement distances between aerial telemetry locations. Olson (1981) found that distances moved between successive aerial locations were 50% greater for elk affected by seismic exploration, and drew firm recommendations for restrictions to be placed on development based on these findings. However, no statistical tests were conducted, and more troubling, the metric used, distance between locations, was not corrected for the amount of time between locations to a movement rate. Thus, distance between locations is really a function of both disturbance level and days between locations, and there may have been an important bias for greater frequency of relocations for the 'treated' group (mean of 2.8 locations/month) vs the 'control' group 0.5 (locations/month). Because movement rates scale inversely with relocation interval (meaning that the longer the movement interval between locations, the 'lower' the movement rate), the observed difference between the treatment and control group is almost certainly a function of sampling design, not treatment effects. Regardless, with ridiculously low sample sizes (n=6 total elk), little reliable inference can be drawn from this study.

In a simulated mining study on elk calves, Kuck et al. (1985) studied the responses of elk calves through radiotelemetry to three treatments of mining, human disturbance, and a control group. Kuck et al. (1985) captured and collared 25 elk in the Dry Ridge area of Idaho, and compared movement rates, resource selection, and calf survival between the groups during summer for 2 years. Disturbed elk moved greater distances, showed strong selection for closed conifer, had reduced fidelity, but there was no difference in survival rates between treatments for calves. The authors conclude that mining exploration will likely cause abandonment of spring calving ranges, but fell short of being able to connect these changes in behavior to demography, most likely because of small sample sizes of collared elk calves (n=25).

In a unique study, Morgantini and Hudson (1985) documented the effects of pipeline construction on movements of elk, moose, and deer in west-central Alberta. Using snow track surveys, Morgantini (1985) documented crossing attempts of 76 ungulate groups of the pipeline during construction. The pipeline was a barrier for 53.9% of ungulate groups that tried to cross them. Elk appeared to be the most successful, while moose were the least successful. Dirt berms did not appear to be a physical barrier to ungulates. The few encounters of ungulates and the pipeline during this study could be due to their avoidance of the development corridor at a larger spatial scale. The pipelines did not alarm the animals that did come in contact with the pipelines, but did act as a physical crossing barrier. The limitations of this study were the short duration, governed by the duration of construction, and the lack of information about the larger spatial scale and any broad-scale avoidance of the entire area (as found by many other studies) by ungulates. Regardless, Morgantini (1985) makes several practical recommendations to maintain periodic openings in pipelines under construction and even underpasses, or overpasses along pipeline to mitigate crossing barriers.

In the closed conifer forested foothills west of Rocky Mountain House Alberta, Lees (1989) studied the movements of 7 radiocollared elk along a pipeline right of way to investigate the effects of recreational disturbance (hiking, ATV's, etc) along the pipeline during winter. Lees (1989) used radiotelemetry, track counts during winter and remote camera's in an observational study design. The results of this study were largely inconclusive, due to the small sample size of collared elk (n=7) and remote cameras (n=5). However, the snow track surveys, which included a much larger sample size of track crossing locations (n=598) showed stronger avoidance by elk of areas within 350m of the pipeline right of way when human activity was high in the fall. Thus, human activity mediated the negative indirect effects of the pipeline on elk. This is the same study area of (Frair et al. 2007, Frair 2005), summarized below.

Finally, Berger (2004) did a literature review on the loss of migration amongst North American ungulates. In the Greater Yellowstone ecosystem, Berger documented 75% declines in ungulate migration for mule deer, elk, and pronghorn due to long-term human caused habitat fragmentation and overhunting. Threats to remaining long-distance migration include energy development, tourism development, sub/urban sprawl, highway mortality and habitat fragmentation.

3.2.3 A Brief Review of Related Studies on the Effects of Human Activities Not Including Energy Development on Elk

3.2.4 Elk-forestry relationships

In a now-classic series of studies in seven replicated sites in Montana, (Lyon, 1979, Lyon 1979, Lyon et al. , 1985, Edge et al. 1985, Edge and Marcum 1985) conducted long-term research into the responses of elk to logging, human recreational disturbance, and climate (Fig. 8). The management implications of these studies were summarized for MTFWP in Lyon et al. (1985), and have provided much of the basis for elk management in Montana ever since. While these studies did not specifically investigate the effects of energy development on elk, they laid the foundation of much of modern elk management in forested mountain systems in the Northwest. As such, their methodologies, approaches, and conclusions offer great insights to MTFWP for understanding the effects of energy development on ungulates in eastern Montana. Although conducted in differing habitats, as I synthesize in the discussion, the general results of avoidance of human activity demonstrated by these studies in forested mountain habitats might be expected to be greater in open habitats. Moreover, I suggest in the discussion that a similarly large scale and coordinated effort will be required to understand the effects of energy development on wildlife as these studies did for elk-forestry relationships 25 years ago.

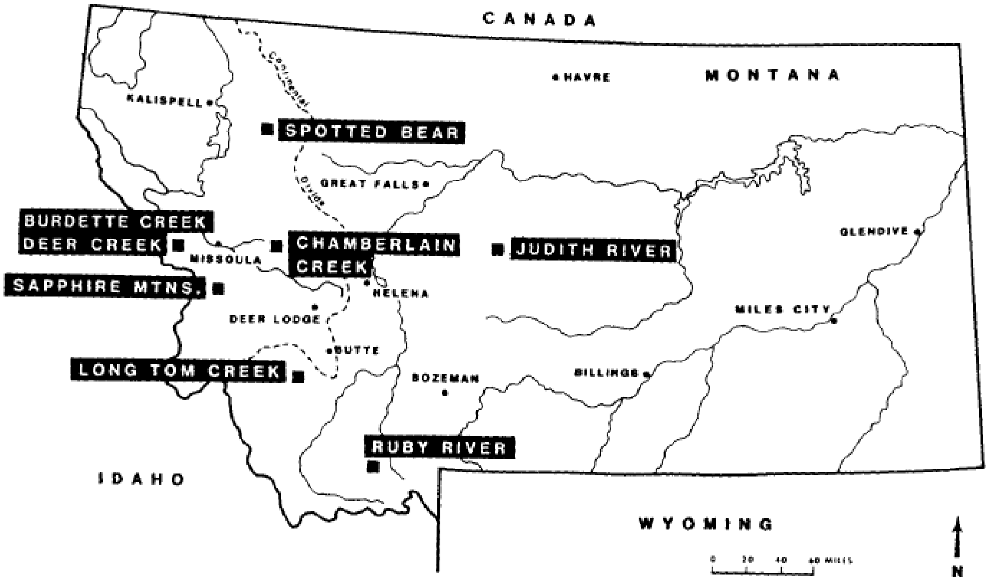


Fig. 8. Locations of the seven replicate study sites in the Montana Cooperative Elk-Logging study 1970-1985, reproduced from Lyon et al. (1985).

Over an eight year period from 1970 to 1977, Lyon (1979a,b) used extensive repeat pellet count surveys to measure the response of elk to roads, cover, and weather in one of the study sites. A total of 2.5 km/km^2 of pellet transects were sampled across the 215km^2 study every year. Elk moved away from areas during active logging operations (Lyon 1979), and avoided areas adjacent to open forest roads especially when forest cover was low such as in open habitats (Lyon 1983). Lyon (1979) recommended reducing human activity on roads to enhance security for elk, and providing elk with a line of sight barrier between disturbances and refugia.

In another Montana study area, Edge (1982) and Edge and Marcum (1985) studied the annual response of elk to logging activities using 39 radiocollared elk by investigating aspects of home range habitat selection, distance to roads and human activity and cover. In the component of the study examining elk habitat selection as a function of human activity, vegetation type and cover, Edge (1982) found elk avoided forest roads with high human activity during all seasons, especially in the absence of cover from the disturbance provided by closed conifer forests and topography. Elk avoided areas within 750m of roads and 1000-1500m of active logging operations. Even highly preferred foraging habitats were avoided within 500m of active logging operations and human activity of all types. Generalizing, Edge (1982) concluded that elk avoided a minimum of a 500m buffer from logging activity. In a unique comparison, Edge found elk were closer to active logging operations on weekends, when logging activities temporarily ceased, than during weekdays, showing a high degree of behavioral flexibility. During the hunting season, when human harvest pressure was greatest on forest access roads, elk avoidance of human activity increased to 2000m of roads. The recommended that road design avoid openings and take advantage of topography to benefit elk habitat effectiveness.

In their home range study, Edge et al. (1985) found that given increased logging disturbance, elk did not expand their home range size. In terms of home range fidelity, elk in disturbed locations were 40% more likely to shift home ranges than the control group (home range fidelity coefficient for disturbed elk = 0.58, for control elk 0.76). Although differences were not statistically significant, this was likely due to the very small sample size used in this analysis; only 10 elk that were tracked between successive years experienced disturbance (In this case, however, the exact sample size used to calculate statistical tests was unclear, to avoid pseudoreplication, sample size should be n=10 elk, but for the general coefficient of fidelity, Edge et al. (1985) used n=62 fidelity coefficients not n=39 different elk). This confusion makes it difficult to conduct meta-analysis on these data.

Other studies followed Lyon (1979) to estimate pellet densities as a function of distances to roads across the western US. In Colorado, for example, Rost and Bailey (1979) studied elk and mule deer. Rost (1979) found increasing pellet densities of elk and mule deer with increasing distance from roads in their shrub steppe ecosystem. Rost (1979) found in Colorado that elk and mule deer avoided areas up to 200m from roads. Lyon (1983) synthesized these results with the results of other studies to develop a general model of habitat effectiveness for elk that modeled % habitat effectiveness as a function of road density. Declines in habitat effectiveness were non-linear – that is, much of the loss of habitat effectiveness occurred in the first 1.6km/km^2 of increasing road densities. This habitat effectiveness model, combined with similar models for cover, formed the foundation of elk management in the western US for decades.

Recent work has started to question the generality and assumptions of the Lyon (1983) road density models, which while beneficial for elk management, have only been tested infrequently. Rowland (2000) tested the generality of the Lyon (1983) road density model by comparing observed habitat effectiveness against expected, under the model in Starkey Experimental Forest and Range in northeastern Oregon. Rowland et al. (2000) used >100,000 telemetry locations from 89 collared female elk to develop habitat selection models as a function of 0.1-km wide distance bands from roads open to human access. The predicted number of telemetry locations, however showed only weak correspondence to the Lyon (1983) habitat effectiveness models. Simulation results demonstrated that the failure of the simple habitat effectiveness models was because of the spatial patterns of roads, a covariate not considered in the original Lyon (1983) models. To be fair, recognition of the critical importance about spatially explicitly habitat models and the role of spatial dynamics in management has only emerged in the recent decade [spatial model; spatial population dynamics; habitat fragmentation], yet these results cast doubt on the generality and value of these earlier, non-spatial models. Regardless of these caveats, Rowland et al. (2000) reaffirms that the management of roads and human activity did influence elk in their study and should remain as a critical consideration in ungulate management, but that spatially explicit models are required to really

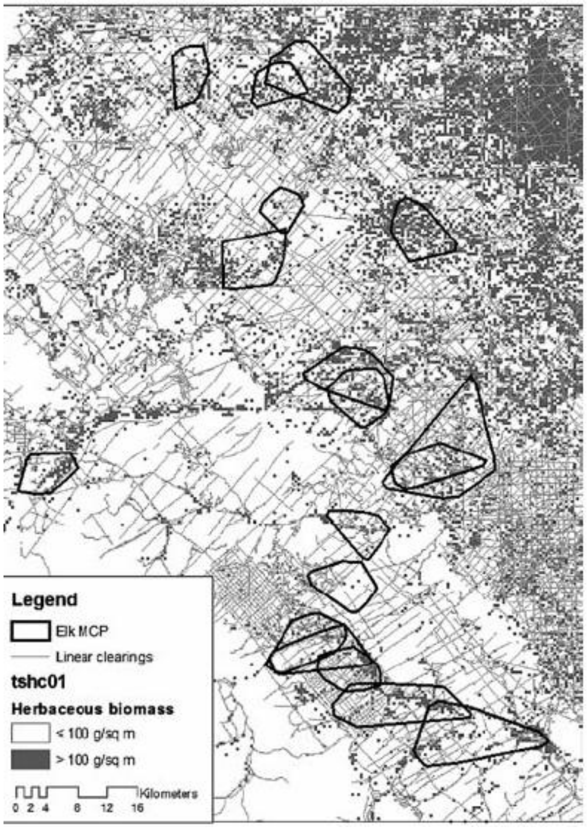


Fig. 9. Portion of the study area for Frair (2005) and Frair et al. (2007) in the central east slopes of Alberta's forested foothills. Home ranges of selected elk shown in black, against seismic cutlines (grey lines) and well sites (dots). From Frair et al. (2005).

capture the response of elk to roads at large scales.

Recent studies build on this paradigm shift in ungulate management that spatially explicit models are required to effectively mitigate the negative effects of human activity at large scales. In a follow up study also at Starkey experimental forest, Preisler et al. (2006) developed new spatially explicit methods, probabilistic flight response analysis, to analyze the effects of off-road vehicle recreation on elk movements. Consistent with previous studies, Preisler et al. (2006) found that elk responded at relatively far distances >1000m to ATV recreation, and that elk movement speeds increased when closer to trails. This study confirms the indirect effects of behavioral displacement by human activity on elk.

In the heavily developed foothills of Alberta, Frair (2005) and Frair et al. (2007) examined the responses of resident (and translocated elk, not discussed here) elk survival and movements to human activities, including seismic exploration cutlines, wellsites, and forestry. Their study area was 17,000km^2 of lower and upper foothills consisting of primarily closed conifer forests that contained over 28,000km of seismic exploration lines and 7,000 wellsites, for average densities of 1.7 km/km^2 of seismic lines and 0.4 wellsites/km^2 ,(Fig. 4) on the higher end of many of the studies reviewed in this literature review. From a movement perspective, Frair et al. (2005) found that elk were more likely to move away from linear seismic lines, and forage and bed at greater distances, respectively, from seismic lines.

To determine mechanisms driving elk movement patterns, Frair et al. (2007) studied survival of >200 radiocollared elk, detecting 104 mortalities (many of translocated elk) from 2001-2005. Elk survival decreased as a function of distance to seismic line (Frair et al. 2007), as a function of increased human caused hunting mortality and wolf predation, both of which selected to be close to roads (e.g. Hebblewhite et al. 2005b, Frair et al. 2007, Hebblewhite and Merrill 2008). But, importantly, humans and wolves use roads and seismic lines differently, roads being more heavily used by human hunters, and seismic lines being more heavily used by wolves. This trade-off likely occurred because of the indirect effect of wolf avoidance of human activity; wolves themselves being hunted by humans (see Hebblewhite and Merrill 2008, Hebblewhite et al. 2005a). From an elk perspective, however, for each

100m increase in distance from seismic lines, elk were 0.68 and 0.78 times less likely (reported as odds ratios, odds <1 are reduced) to die from wolves and humans, respectively. Thus survival increased with distance away from seismic lines. When considering roads, however, mortality risks contrasted for wolf and human hunting. For every 500m increment farther from roads, elk were 0.84 less and 1.34 times more likely to die from human hunting and wolf predation, respectively. Failing to separate out mortality sources masked the different responses to different types of mortality and how different predators (human, wolf) used the landscape differently.

3.2.5 Effects of Hunting and Recreation on Elk

The mechanism behind road avoidance by elk in the above studies was hypothesized to be due to increased hunting mortality associated with open roads. This mechanism has been corroborated by numerous studies across western North America since (Unsworth et al. 1999, Frair et al. 2007, Cole et al. 1997, McCorquodale 2000). As an example, Morgantini and Hudson (1980) studied the effects of human disturbance on elk in a montane grassland in the eastern slopes of Alberta from 1977-1979 using a combination of observations, pellet surveys, diet studies, and telemetry on radiocollared elk. Their study area contained energy development, but this study specifically focused on the effects of hunting pressure on elk. They found, similar to the studies in Montana, that elk avoided human activity more during the hunting season, shifting to denser cover farther from roads, and adapted their activity patterns to forage only during dusk and dawn.

Reasonably strong experimental evidence supports an increased mortality risk to elk from human hunters on roads. Cole et al. (1997), tested the effects of an unreplicated (n=1) experimental road closures on survival of Roosevelt elk (*Cervus* *elaphus nelsonii*) in Oregon from 1991-1995. Cole et al. (1997) determined home range size, movement rates, and survival differences between the pre- and post- road closure periods for 41 radiocollared adult female elk in a before after design without an contemporaneous control. By removing access to 128km of BLM roads (35% of roads in study area), Cole et al. (1997) documented a 12% reduction in home range size, a 18% reduction in daily movements, and a 7% reduction in mortality for elk, although the difference in survival was not statistically significant with only 6 mortalities observed during the study. Limitations of the experimental design are 1) the lack of adequate controls for the treatment period – improvements to adult survival and reductions in home range size or other variables could have been because of more favorable climatic conditions (spring precipitation, etc.) or other unmeasured variables; 2) small sample sizes for making strong population inferences. In survival estimation, the number of mortalities strongly determines the level of confidence in survival estimates, and in long-lived ungulates with high annual survival rates, determining population level impacts requires substantial sample sizes. Despite the fact that this study is often cited as compelling evidence for the beneficial effects of road closures, these two weaknesses reduce the scientific merit of this study. Similar studies in Montana and elsewhere also examined the effects of hunter road restrictions on elk, including Basile (1979), but few made the difficult but important connection to demography that Cole et al. (1997) attempted.

Human recreation besides human hunting from roads can also affect elk populations, a subject that has been the focus of numerous studies and literature reviews in itself (Bjornlie and Garrott 2001, Cassirer et al. 1992, Joslin and Youman 1999,Oliff et al. 1999). Elk and other wildlife may view human recreation as a form of predation risk even without direct mortality because of indirect behavioral mechanisms (Frid and Dill 2002,Geist 2002). For example, Millspaugh et al. (2001) showed clear physiological stress responses of elk to proximity to roads and when in areas with higher road densities. Here, I only review a few recent key studies that exemplify proper experimental design and provide a beacon of scientific rigor to biologists considering improving studies of the effects of energy development on wildlife.

In a series of exceptionally well planned studies in the Beaver Creek and Vail areas of Colorado, Phillips and Alldredge (2000) and Shivley et al. (2005) conducted a well designed experimental (albeit only n=1 replicate) test of the effects of spring/summer hiking recreational disturbance on elk on calving and summer ranges. Phillips and Alldrege (2000) and Shivley et al. (2005) maintained a total sample of 75-85 radiocollared adult female elk across both the control and treatment areas and applied hiking disturbance to the control group in a before-after-control-impact (BACI) design as follows. In 1995, no treatment was applied to the treatment area (before), and the disturbance was applied in 1996 and 1997 (see discussion), then not applied in 1998 and 1999. In the control area, no treatments were applied. They then compared the effects of hiking disturbance on calf:cow ratio's, a key indicator of population performance in ungulates and elk in particular (Raithel et al. 2007,Gaillard et al. 2000).

Calf:cow ratio's were similar before hiking disturbance was applied in 1996. Calf:cow ratio's steadily declined for the two years of treatments for an average reduction in calf:cow ratio of 0.173, or 17 calves:100 cows, (95% CI: -0.32 to -0.03). Population modeling revealed that this reduction in calf survival could reduce population growth rates from 7%/year to 0%/year, confirming the substantial negative impacts of human disturbance during spring and summer to population dynamics of elk. On the basis of this exceptionally well designed study, the authors of both studies make strong recommendations to protect spring calving habitat, concluding "to ignore potential effects of human-induced disturbance to elk during calving seasons is to risk declining reproductive success in elk populations" (Phillips and Alldredge 2000).

Extending these results to the effects of human development in general, an observational study of the effects of increased ski resort development in the Vail area of Colorado (Morrison et al. 1995) showed that during ski area development, when human disturbance was the highest, elk avoided human activity and the development site more than afterwards. Elk use after development was still lowest when human activity was highest, indicating that while elk habituated to development to some degree, there may be long term negative impacts. These two examples illustrate the benefits of conducting well designed experimental studies to guide the interpretation of less intensive observational studies.

Table 2. Review of scientific literature on the effects of energy development on Elk, summarizing study authors, location, vegetation type, species (Aa- *Antilocapra* sp., AlAl – *Alces alces*, Ce- *Cervus elaphus,* Oh- *O. hemionas*, Oc- *Ovis canadensis*), whether the study was peer reviewed or not, study area size, duration, development type, study design and sample size, general results and management recommendations.

Authors, location, Veg. type	Spp.	Peer Review	Study Area Size, Duration	Development Type	Study design & size	General Results	Management Recommendations
Bennington et al. 1981 MI, Mixedwood	*Ce*	No	512 km^2 and 1.4 years	Oil drilling/well pumping	Observational, aerial surveys, track surveys, n=N/A	Short-term decrease in activity following oil drilling, temporary (2-4 wk.) relocation after development, no significant diff. between pre-drilling and post-drilling activity.	Avoid high impact habitat sites such as calving grounds; habitat mitigation required.
Cole et al. 1997 OR, Mountain	*Ce*	Yes	972 km^2 and 3 years	Roads and human hunting	Experiment, radio-telemetry, n=41*	Core area and home range size, as well as movement rates decreased and elk survival increased with experimental road closures.	Increase road removal and road management areas, decrease illegal hunting on open roads, restrict human access to roads.
Edge et al. 1982 MT, Mountain	*Ce*	Yes	Unk, 5 years	Logging	Observational, radio-telemetry, n=36*	Avoided open habitats and logging especially in areas of high human activity.	Construct roads with cover and topography in mind, manage human recreational access, greatest impact in summer.
Edge et al. 1985 MT, Mountain	*Ce*	Yes	Unk, 5 years	Logging, human recreation	Observational, radio-telemetry, n=39*	Elk did not change home range size or fidelity with logging.	Logging activities limited to unoccupied seasonal habitats & logging restrictions the minimize time and overlap with elk winter ranges.
Frair et al. 2007 AB, Foothills	*Ce*	Yes	17000 km^2 and 5 years	Siesmic, roads, wells, forestry	Comparative, GPS telemetry, n=40 resident elk	Mortality increased closer to roads by humans, closer to seismic cutlines by wolves. Landscape-scale changes from cumulative impacts in wolf and human predation risk survival.	Manage for lower human use on roads all year to improve elk survival. Impacts were cumulative with other land use changes from forestry.

Table 2. Cont.

Authors, location, Veg. type	**Spp.**	**Peer Review**	**Study Area Size, Duration**	**Develop-ment Type**	**Sample design & size**	**General Results**	**Management Recommendations**
Frair 2005	*Ce*	Yes	17000 km^2 and 5 years	Seismic, roads, wells, forestry	Comparative, GPS radio-telemetry, n=40 resident elk	Effects of roads were compounded by attraction to clearcuts associated with roads, elk avoided clearcuts within 200m of a road. Road network design became increasingly important as road density increased and accounted for as much as 30-55% of the change in mortality risk	Availability of core areas declined to 50% above road densities of 0.5-1km/km^2, and elk could not tolerate road densities >1.4km/km^2. Road network design that minimized roads and restricted human access could minimize risks to elk.
Gillin 1998 WY, Mountain	*Ce*	Yes	Unk, 2.2 years	Seismic exploration, roads	Experiment, radio-telemetry, n=21	Elk were temporarily displaced during and after seismic activity for up to two weeks, but returned later.	Seismic spaced min 2, max 7-10 days apart; designated helicopter flight corridors w/ altitudes > 150m; avoid calving areas, foraging areas and open meadows; spring impacts greatest.
Hiatt et al. 1982 WY, Mountain	*Ce, Oh*	No	101 km^2 and 0.25 years	Oil well	Comparative, radio-telemetry, Unk	Elk and mule deer shifted home ranges away from the well site, did not avoid access road.	Late winter spring were the greatest impact seasons
Hayden-Wing Associates 1991 Review	*Aa, Oh, Ce*	No		Gas, oil, seismic exploration	Review, n=N/A	N/A, Literature review	Recommend restriction of exploration on occupied winter range from Nov 15 to April 30 as a precautionary principle Winter impacts greatest
Hayden-Wing Associates 1990 WY, shrub steppe	*Ce*	No	96 km^2 and 11 years	Active wells	Comparative, aerial elk surveys, n=11	No significant difference in elk population size over 11 years in response to drilling, but changes in distribution varied widely.	Need for long-term studies; recommended putting wells in low visibility areas; avoidance of calving and winter ranges
Irwin and Gillin 1984 WY, Mountain	*Ce*	No	Unk, 1 years	Seismic exploration	Observational, radio-telemetry n=21	Elk partially avoided calving ranges after seismic, migrating to summer range. Elk avoided disturbance using topography and cover.	Restrictions on development during calving on calving ranges, road alignment should minimize visibility of the road using cover and topography.

Table 2. Cont.

Authors, location, Veg. type	Spp.	Peer Review	Study Area Size, Duration	Develop-ment Type	Sample design & size	General Results	Management Recommendations
Johnson 1980 WY, Mountain, sagebrush steppe	*Ce*	No	Unk, 1 years	Oil and gas wells.	Observational, aerial telemetry & aerial surveys, n=4-56	Elk were affected by activity on the access road; cows moved calves at earlier age; elk were displaced away from drilling rig in 1979.	Minimize drilling activities in spring and winter range, road mitigation required.
Johnson and Wollrab 1987 WY, sagebrush steppe	*Ce*	No	Unk, 8 years	Natural gas field	Comparative, radio-telemetry, n=16	80% of surveyed elk were on gas field prior to drilling; only 39% were on the field during drilling. Calving ground was also abandoned during the intense drilling.	Avoid drilling on calving and winter ranges.
Johnson et al. 1986 WY, mixed	*Ce*	No	25.9 km^2 and 3.25 years	surface coal mine	Experimental, radio-telemetry n=64*	All measured variables showed no significant difference between control and mine study groups, winter impacts greatest	None.
Knight 1981 MI, mixedwood	*Ce*	Yes	56 km^2 and 1 years	Seismic exploration; oil well drilling	Comparative, radio-telemetry n=12	Elk moved away from seismic: terrain and vegetation type had no effect. No significant difference in elk home ranges with/without disturbance, no correlation between distance to disturbance and mean daily movements.	Need to study effects of pipelines on wildlife, timing restrictions for seismic exploration to avoid winter range and calving.
Kuck et al. 1985 ID, Forests	Ce	Yes	350 km^2 and 2 years	Simulated mining & human disturbance	Experimental, radio-telemetry n=25	Disturbed calves moved greater distances, used larger areas, showed greater use of coniferous forest, and lacked selection for favorable physiographic parameters. Cow/calf pairs abandoned calving areas, Winter survival between groups and between years was similar.	Development restrictions during calving, spring summer greatest impacts.

Table 2. Cont.

Authors, location, Veg. type	**Spp.**	**Peer Review**	**Study Area Size, Duration**	**Develop-ment Type**	**Sample design & size**	**General Results**	**Management Recommendations**
Lees 1989 AB, Foothills	*Ce*	No	Unk, and 1.25 years	oil pipeline	Observational, n=7* collars, 5 cameras, n=568 tracks	Telemetry: inconclusive; tracks: avoidance of human impacts; cameras: inconclusive, fall impacts greatest	Control public use and access through gating, improvements to forage on pipelines.
Lyon 1979 MT, Mountain	*Ce*	No	215 km^2 and 8 years	logging; roads	Observational, pellet surveys, n= Unk	Elk consistently moved away from active logging.	Manage roads to reduce human hunting, avoid logging in winter, spatial overlap with elk winter range.
Morgantini and Hudson 1980 AB, Mountain	*Ce*	No	35 km^2 and 0.5 years	Roads and human hunting	Observational, behavioral observations, n= Unk	Elk avoided roads in day, forage closer to them at dusk and dawn. Elk avoided the open grasslands near roads.	Restrict human activity to reduce negative impacts of roads.
Morgantini 1985 AB, Foothills	*Alal, Ce, Oh, Ov*	Yes	Unk, 0.33 years	oil pipeline	Observational, Snow track surveys, n=Unk	Pipeline was a barrier for 53.9% of ungulate groups that tried to cross them. Elk were least affected, moose the most impacted by the pipeline.	Have periodic openings, underpasses, or overpasses along pipeline to mitigate it as a crossing barrier.
Olson 1981 MT, Mountain	*Ce*	No	503 km^2 and 0.5 years	Seismic exploration, natural gas	Comparative, radiotelemetry, n=4	Elk avoided visual disturbances more than auditory; movement rates increased closer to disturbance.	Winter activity should be kept to a minimum; have specified flight paths for helicopters to minimize disturbance
Phillips and Alldrege 2000 CO, Mountain	*Ce*	Yes	500 km^2 and 3 years	Human recreation on trails.	BACI, radio-telemetry n=80	Average calf production was 0.23 calves/cow lower for elk disturbed by humans than control elk, reduced population growth rate 7%.	Calving-season closures for all human activity in elk habitat.
Powell 2003 WY, sagebrush steppe	*Ce*	No	2521 km^2 and 3 years	active oil and gas wells, roads	Observational, n=40*	Elk avoided active wells and roads by 2 km in summer, showing 73% less use than expected.	Summer impacts greatest, seasonal road restrictions in summer habitat.

Table 2. Cont.

Authors, location, Veg. type	Spp.	Peer Review	Study Area Size, Duration	Develop-ment Type	Sample design & size	General Results	Management Recommendations
Rowland et al. 2000 OR, Starkey, Mountain	*Ce*	Yes	77.6 km^2 and 3 years	roads	Observational, radio-telemetry n=89*	Elk consistently selected areas away from open roads in both spring and summer. Model predictions of simple habitat effectiveness models corresponded only weakly with observed habitat effectiveness values.	Spatial distribution of roads must be considered for habitat effectiveness models for evaluating impacts. Summer road restrictions needed. Spring summer impacts greatest.
Sawyer et al. 2007 WY, shrubsteppe, grasslands	*Ce*	Yes	2517 km^2 and 2 years	n/a	Observational, GPS telemetry, n=33* (55 VHF collars in validation sample)	Elk selected for summer habitats with higher elevations in areas of high vegetative diversity, close to shrub cover, northerly aspects, moderate slopes, and away from roads. Winter habitat selection patterns were similar, except elk shifted to areas closer to roads.	Management of roads and related human disturbance is an important consideration for managing elk populations. Summer impacts greatest
Shivley et al. 2005 CO, Mountain	*Ce*	Yes	500 km^2 and 2 years	Human recreation.	BACI, radio-telemetry, n=145	Productivity rebounded following release from disturbance, and full recovery was achieved by the second post-disturbance year.	Selective closures, or at least restrictions on recreational activity, may be warranted during calving season, when greatest impact occurred
Van Dyke 1996 MT, grasslands	*Ce*	Yes	500 km^2 and 4years	Active oil well	BACI, n=10	Minimal effect of drilling on elk home range use in a low density drilling area. Elk used cover during drilling.	
Ward 1986 WY, sagebrush steppe, grasslands	*Ce*	No	Unk, 4years	Seismic exploration	Observational, few radio-collared elk, surveys, etc. n=Unk	Elk avoided human activity depending on line-of-sight; without topography, elk moved 3.2 km; with topography, 800 m. Elk returned to areas of disturbance a few days after activity was concluded.	Road, wellsites should be aligned in areas of low visibility in topography out of line of sight.

3.3 Pronghorn Antelope (*Antilocapra americana*)

3.3.1 Grasslands

In one of the earliest studies of pronghorn considered in this literature review, Bruns (1977) investigated general patterns of pronghorn habitat use, movements, and effects of human developments using ground and aerial observational methods including snow tracking and behavioral observations. Bruns (1977) focused on short grass prairie in south eastern Alberta from 1968-69 during an exceptionally severe winter. He found that pronghorn movements were restricted during winter months, and selected habitats that minimized snow depths during winter, had lower winds, and with softer snow that made pawing through snow to forage easier. Severe snowstorms caused rapid, long distance movements. Average herd sizes were 38 animals. Pronghorn often used plowed roads as movement corridors, but suffered effects of habitat fragmentation from fences and gates. Management recommendations included barbless wire fences, pronghorn specific designs in important migration and travel routes, and keeping gates open to facilitate movements.

Oil and gas exploration in the little Missouri grasslands have negatively impacted habitat for Mule deer, Elk, and White-tailed deer, reviewed in a study by Girard and Stotts (1986). Girard et al. (1985) summarized the effects of energy development as impacts during development and exploration phases, chemical spills that upset sensitive prairie grassland and stream ecology, and displacement of wildlife species. Approximately 1% of the entire area considered was physically lost because of energy development, and an undetermined area surrounding development was avoided by these ungulate species. Girard (et al. 1985) emphasized how critical site reclamation was for sensitive grasslands, the critical task of suppressing non-native invasive weed species, the danger of saltwater pond (associated with drilling operations) blowout on downstream systems, and the negative effects of H_2S (hydrogen sulphide) on wildlife species. I return to this important and understudied area in the discussion.

In a study that could be useful as a baseline to compare against development underway in eastern Montana, Armstrup (1978) studied the habitat use, movement patterns, and home range use of 102 pronghorns marked with VHF or visual collars on the border of Montana and Wyoming in and around the Powder River basin from 1976 to 1977. Armstrup (1978) found wide variation in selection for vegetation types seasonally, and that selection was largely a function of available vegetation. This corresponds with the concept of functional responses in resource selection that emphasize 'critical' habitat changes across regional gradients in availability (Mysterud and Ims 1998,Hebblewhite and Merrill 2008). Topography was not a big driver of pronghorn habitat selection. The most significant finding of this study was that all marked pronghorn used a completely different winter range during 1976 than in 1977 – confirming that long-term studies are required to evaluate key habitats and even to define areas of occupancy.

3.3.2 Shrub-Steppe

Approximately 10 studies on pronghorn ecology and energy impacts in sagebrush-steppe ecosystems were reviewed from a total of 4 study areas; the Northern Range of Yellowstone National Park (White et al. 2007a), the Upper Green River Basin (Berger 2004, Berger et al. 2006, 2007,Sawyer et al. 2002, 2005b,2006), in the Rattlesnake hills in Wyoming (Easterly 1991), and on a reclaimed coal mine in northeastern Wyoming (Medcraft and Clark 1986). The series of studies by Sawyer and colleagues in the Upper Green River focused on both mule deer and pronghorn, and so are summarized below in the combined section.

The series of studies by Berger and colleagues (Berger 2004, Berger et al. 2006a,b, 2007), examine the response of pronghorn to energy development in the Upper Green river basin overlapping the study area of Sawyer et al. (2002). This area is underlaid by the Jonah and Pinedale Anticline natural gas formations that are estimated to contain >10 trillion cubic feet of natural gas and coal bed methane deposits, and is undergoing rapid expansion in oil and gas development. Energy development only started in 2001, so all of the studies of Berger, Sawyer and colleagues should be considered as assessing the early impacts of energy development.

The studies of Berger and colleagues were initiated in fall 2002 as a pilot study investigating migration in pronghorn (see Berger et al. (2004, 2006) summarized below), the study was expanded in 2005 to a five-year study of the effects of natural gas development on pronghorn behavior, migration, habitat selection, and, ultimately, the population consequences of development. Methods involved collaring ~50 pronghorn/year split evenly between a control (undeveloped area) and treatment (energy development area) area. In 2007, they increase the sample size to 100 VHF collars to estimate survival rates and to provide better longitudinal data on survival. They recovered 48 GPS collars in 2005 and 42 GPS collars in 2006, and in these preliminary progress reports, compare resource selection between the control and treatment groups. In their first (Berger et al. 2006) and second-year progress reports (Berger et al. 2007), the authors emphasize that results are preliminary and subject to change given long-term responses and final analysis. Regardless, their interim results can provide some important information about pronghorn responses to increasing development on winter ranges.

Berger et al. (2006, a,b) report that the overriding natural factor influencing distribution of pronghorn on the winter range was snow depth – pronghorn selected 60% shallower snow depths than available throughout the study area (e.g., 12cm versus 19cm). In terms of resource selection, while some individual animals continued to select habitat in the energy development areas, some animals avoided developed areas. At the population level, however, the authors did not find pronghorn were avoiding developed areas at the current levels of development. Identification of core areas of use by pronghorn, dictated by patterns in resource availability, may be useful tools to identify areas that are important to pronghorn for future energy development planning. From a population perspective, the authors found no differences in survival rates or body measurements of pronghorn between the control or treatment groups. While their results suggest energy development does not influence pronghorn within the Upper Green River Basin, the authors caution that results are preliminary, winter severity has been mild during the study (impacts may be greater during deeper winters given pronghorn selection for shallower snow), the area of most intense development at present are not within prime pronghorn habitat, and responses may be expected to increase over longer periods of time for long-lived ungulates than the two year time-window reported on to date. A long-term commitment to understanding the effects of energy development on this and other populations of ungulates is required. Regardless of the equivocal results of energy development on winter ranges, these studies documented substantial potential impacts of energy development on migration both within this study area, and at the regional scale.

Berger's (2004) literature review on the loss of migration also mentions pronghorn migratory declines, especially in the GYE, where approximately 75% of all migrations have been lost. Berger (2004) illustrates the problem with a case study involving their long-term pronghorn study in the Pinedale area of WY. Both residential development and future potential energy development threatens one specific migratory corridor pinch point, the Trapper's Point bottleneck, where the migration corridor narrows to less than 800m. In a follow up study to this literature review, Berger et al. (2006) confirm that this particular migration corridor, from the Upper Green River through to Teton National Park, has likely been used for over 6000 years. Using archaeological data that confirms the presence of pronghorn in this migration corridor, Berger et al. (2006) argues that this migration route has likely persisted uninterrupted for at least 6000 years and likely since the end of the Pleistocene. Only by creating large scale migration corridors that are protected from development or managed specifically to mitigate energy development, will long-term migration, a critical ecological process that is declining across the Rocky Mountain west, persist.

The importance of migratory corridors for pronghorn is also emphasized by a recent study in Yellowstone National Park by White et al. (2007). Movements of 44 radio-collared pronghorn over 6 years revealed a similar 'pinch point' in the migration corridor between summer and fall ranges which resulted from topographic constrictions, habitat requirements of pronghorn for open habitats, and fidelity to historic migration routes. Development proposed within the park for increased tourist facilities and buildings threatens this migration corridor. White et al. (2007) also showed that this population was partially migratory with approximately 70% migratory, and 30% resident.

Migratory pronghorn showed some fidelity to summer ranges, but 20% switched between years and switched strategies from year to year from migrant to resident. This study clearly emphasizes how little we know about migration in most populations, and that migration is likely a condition dependent strategy that depends on density, population history, climate, and, potentially, disturbance regimes. Management implications of this study are that it takes a long-time to document migration patterns and that, combined with the studies of Berger (2004) above, pronghorn seem especially vulnerable to development within migration corridors.

3.3.3 Semi-desert: effects of military activities

The Sonoran pronghorn (*Antilocapra antilocapra sonoriensis*) is the most endangered subspecies of pronghorn, with population declines to <33 animals as recently as 2003 (Krausman et al. 2005). Despite being listed as an endangered species for over 30 years, reasons for the population declines are relatively unknown, but though to be linked to habitat and forage degradation, loss of water sources because of hydroelectric developments, and human development. Forty percent of identified Sonoran pronghorn habitat occurs in military lands in southwestern Arizona, and a series of studies investigated the effects of military overflights and ground activities on pronghorn habitat use, behavior, hearing, and potential population consequences (Krausman et al. 2004, 2005, Landon et al. 2003). The most comprehensive study compared behavior of pronghorn on the military base to baseline behavior of animals in the closest population of pronghorn without military activity, albeit from a different subspecies. The study primarily relied on behavioral observations of pronghorn responses to human activities. Pronghorn exposed to military activity foraged less, stood alert and moved more than pronghorn not exposed to military activity. Pronghorn did not appear to respond to military overflights, and the study found that ungulates do not hear sounds from military aircraft as well as humans do.

These results contrasted with the results of (Landon et al. 2003) that found habitat use of 31 radiocollared pronghorn tended to be in areas with lower noise levels from military activities, although this study apparently pseudoreplicated, confusing the # of locations of animals with the true sample size instead of the # of animals. Landon et al. (2003) acknowledge that more detailed habitat selection studies are certainly needed before firm conclusions could be drawn. Acting on these recommendations, Krausman et al. (2005) investigated habitat selection of Sonoran pronghorn using detailed behavioral observations (n=1203) of pronghorn collected over a 3 year period from 1999-2002. Sonoran pronghorn showed stronger selection for burned sites and sites previously disturbed by military activity (bombing ranges, fires, etc.) over undisturbed sites. They speculate that increase forage production, visibility and ease of movement all contribute to pronghorn selection for disturbed sites, and that declines in military activity that simulate natural disturbance may actually be detrimental to pronghorn. Overall, Krausman et al. (2004, 2005) found few impacts of military activities on Sonoran pronghorn, but conclude that the population remains in serious danger of extirpation and immediate conservation actions are needed.

3.4 Mule Deer (*Odocoileus hemionus*)

3.4.1Sagebrush-Steppe and Grasslands

Berger's (2004) literature review on the loss of migration amongst North American ungulates also has implications for mule deer and energy development. In the Greater Yellowstone ecosystem, Berger documented 75% declines in ungulate migration for mule deer, elk, and pronghorn due to long-term human caused habitat fragmentation and overhunting. Threats to remaining long-distance migration include energy development, tourism development, sub/urban sprawl, and highway mortality and habitat fragmentation. Large scale migration corridors that are protected from development or managed specifically to mitigate energy development are needed to protect the critical ecological process of long-term migration which is declining across the Rocky Mountain west.

In a series of studies on the effects of energy development in the same Jonah-Pinedale Anticline project area of western Wyoming, Berger and colleagues and Sawyer and colleagues conducted a series of related studies on the effects of energy development on mule deer and also pronghorn to a lesser degree (Sawyer et al. 2005a,b, 2006, 2007). This area is a winter range for large numbers of elk, mule deer and pronghorn and habitat for animals migrating from the entire Upper Green River Basin area, approximately 15,000km^2. Initial studies focused on migration of radiocollared mule deer (n=158) and pronghorn (n=32), and found seasonal migrations for 95% and 100% of all collared animals ranged an average of 84 and 177 km straight line distance between seasonal ranges. This study also noted the potential for energy development impacts on migration corridors, and documented the same narrow pinch point for the migration corridor of pronghorn migrating from the winter range to summer ranges in Grand Teton National Park that Berger et al. (2006, a,b) describe. The authors conclude, with similar recommendations as in other migratory ranges, to minimize development, remove barriers to migratory movements such as fences and pipelines, and potentially develop seasonal restrictions to avoid the peak months of migratory movements in May/June and October/November. This study echoes the results of Berger (2004), who found that impacts on migratory ranges may affect a huge area surrounding the localized development, and requires a regional-scale, cumulative effects assessment approach.

Focusing on winter range impacts was the focus of the studies by Sawyer et al. (2005b, 2006) collectively called the Sublette Mule deer study. The study was started in 1998 to examine the ecology of mule deer home range use, habitat selection, migration routes and demography during a pre-development phase that ended in 2001. From 2001-present, the study entered the second phase as a long-term study on the effects of energy development within the Pinedale area on mule deer ecology in an experimental comparison of areas with and without energy development. With the pre-data collected in phase 1 and two treatment areas in phase 2 (with, without development), this study represents a well designed before-after-control impact study, albeit unreplicated.

Before development, the Sublette Mule deer population was a healthy and productive population, with adult female survival rates (0.85, n=14) and fawn:doe ratio's (>75:100) indicative of a growing population (Unsworth et al. 1999). In 2002, mule deer densities were similar between the control and energy development treatments, but have been diverging since 2002. In the developed area, mule deer densities declined significantly by ~47% over a 4-year period ending 2005, whereas in the control area, there was no negative trend and mule deer densities were constant and similar to pre-development density on the treatment area. This trend in density is suggestive of a demographic impact of energy development, yet survival differences between adult female and overwinter fawn survival were not statistically different between the two areas, although overwinter fawn survival tended to be higher, the differences reported to date in their preliminary progress report were not statistically different. Sawyer et al. (2005) speculate that the lack of demographic difference between treatments may be because 1) small scale demographic differences could explain the differences in population trend, but are preliminary and influenced more by small sample size, and will be verified at a later date by more detailed analysis, or 2) differences were driven by emigration or dispersal from the developed areas. Migration routes were also identified, as discussed above, in this first phase.

From a habitat perspective, Sawyer et al. (2006) reported expanding energy development over a 5-year period with an increase of 95km of roads, 324 ha of well pads, and a total of ~400 ha of lands directly lost to development footprints within the study area, an increase in density of 0.12km/km^2 and ~0.3 wells/km^2 (considering the study area size just the Pinedale Anticline project area of ~800km^2). Effects of energy development are summarized in their 2006 Journal of Wildlife Management paper (Sawyer et al. 2006), where they evaluated the effects of energy development on VHF and GPS collared mule deer collared from 1998 to 2003 over the first three years of development. Sample sizes of VHF and GPS collared mule deer ranged from 7-45 / year of the study. Mule deer avoided areas close to energy development during this study, responses to development occurred rapidly within 1-year of development, and avoidance of energy development increased over the course of the 3–year study. Sawyer et al. (2006) found lower predicted probabilities of use within 2.7 to 3.7 km of an oil or gas well sites, confirming that indirect effects of habitat loss from energy development were much greater than the loss of the direct footprint of energy developments. Over the course of the study, areas that were classified as high quality habitat before development changed to low quality, and vice-versa, showing that mule deer shifted habitats away from favored high quality habitats because of energy development. Presumably, these population level habitat selection responses will eventually have important population implications to the total area of high quality habitat available in the study area. The authors recommend such demographic studies, as well as activities that reduce the footprint of energy development including; 1) directional drilling from single well pads to multiple gas sources to reduce surface impact, 2) limiting public access, 3) developing road networks with the goal of minimizing new road construction, and 4) guidelines to minimize human disturbance during the winter and on designated high quality ranges.

Several reviews of the effects of energy development, with specific focus on mule deer or pronghorn, were also reviewed. Bromley (1985) reviewed the effects of energy development in wildland environments for the USFS, and provides an annotated bibliography similar to this review, including more broadly, the effects of all human activities on wildlife. Generally, she makes the following conclusions; 1) many results are conflicting, yet few studies have quantitatively shown the effects of human activities on population dynamics of wildlife, likely because long-term demographic studies have been extremely rare in the environment; 2) It is often difficult to separate out naturally induced variation in response variables from human disturbance without adequate baseline (pre-development) data and experimental controls; 3) severity of the impacts of energy development are often site-specific and will require localized mitigation strategies in many cases; and 4) Effects of energy development may be most critical during sensitive periods including winter, spring calving, migration corridors, and for social species (no study reviewed in this review was actually replicated).

In a study on the effects of human activity on mule deer in the grassland and pine break vegetation communities in southeastern Colorado, Stephenson et al. (1996)

examined home range use and fidelity in response to military activity during ground training exercises over a three year period. Human activity during military exercises was extreme; during the seven 2-3 week military exercises, between 2624-6619 humans in 854-2397 vehicles used the 1040km^2 study area. They used a comparative design where home range dynamics and fidelity were compared between times with and without human activity for 71 radiocollared female mule deer. Mule deer female and fawn home ranges were larger during military activities during winter and summer. However, only the 50% core areas used by mule deer males were larger during military activities. Forty percent of female deer shifted home ranges between military activities. This study shows that intense human activity can have large impacts on patterns of space use. However, the limitations of this study are the extreme human activity levels observed – few energy developments even at peak construction periods, would approach these human disturbance levels. Secondly, while this study showed large changes in home range behavior, they did not investigate population impacts.

3.4.2 Mountain

Freddy et al. (1986) conducted some comparative trials (without controls) to compare the effects of human hikers and snowmobiles in Colorado from 1979 to 1980 within a mule deer winter range. They compared the responses of 7-11 mule deer to n=67 approaches to hikers and snowmobiles and documented the level of response. Mule deer took flight in response to snowmobiles at a greater distance, but showed a longer duration of response to human hikers than to snowmobiles, and showed a high response, running, more often to hikers than snowmobiles. Based on energetic calculations, each disturbance event cost between 0.2-5% of the daily metabolic requirements of mule deer. When fleeing from hikers, deer moved an average of 907m, and consumed more energy than when responding to snowmobiles. Freddy et al. (1986) concluded that human activity on winter ranges should be severely restricted to minimize negative impacts. Limitations of this relatively well thought out study include psuedoreplication and small actual sample sizes. Sample sizes for tests were considered to be individual approach trials, whereas the true sample unit was the individual radiocollared deer. Therefore, a mixed-model that accounted for deer as the sample unit should have been employed Gillies et al. (2006) and this may have affected results because of the lower effective sample size of 7 to 11 animals.

Evaluating the potential population responses of mule deer to energy development will be difficult because of broad scale declines in mule deer productivity across western North America (Gill 2001,Unsworth et al. 1999). Gill et al. (2001) reviewed the factors causing declines of mule deer populations in Colorado, and concluded declines could be caused by the following factors acting synergistically; 1) competition with increasing elk populations, 2) density dependence in vital rates caused by historic high population densities, 3) long-term declines in habitat quality for mule deer because of changes in fire history regimes in forest and shrub-steppe ecosystems, 4) overharvest in some key areas, 5) increasing predator populations, and finally, 6) diseases, such as chronic wasting disease. Co-authoring the review of causes of mule deer declines were Dr. N.T. Hobbs, Dr. G.C White and other noted experts in mule deer and population biology of ungulates. Given the difficulties of disentangling all these potentially interacting and confounding influences on mule deer population dynamics, the report concludes with a series of recommended large-scale adaptive management experiments designed to test the main hypotheses of predation and habitat change. The authors emphasize that long-term (6-8 year), large–scale (WMU scale, 1000km^2) will be required to rigorously assess reasons for mule deer declines. The recommendations of this study are particularly relevant for considering the effects of energy development on large ungulates. To rigorously link energy development to changes in demography, long-term, large-scale, and well funded adaptive management experiments will be required.

From 1980 to 1981, Ihsle (1981) worked with MTFWP and the BLM to study the population ecology of mule deer along the east slope of the Rockies west of Choteau to determine the effects of oil and gas drilling and development on mule deer. There study occurred early in development under extremely low densities of development – less than 0.003 wells/km^2 had been constructed within their 2725 km^2 study area at the beginning of the study, and their general results was almost no impacts of energy development on mule deer. They radiocollared 78 mule deer and considered home range, movement, habitat selection, migration, and fawn:doe ratio to determine the effects of energy development in an observational correlation-based study design. They found no effects of development, generally because oil wells were restricted to a small part of the study, development density was very low, and the large spatial scale of the study area. Limitations of this study were the lack of a suitable treatment effect of development given the huge study area size. Perhaps focusing just on movements or habitat selection by mule deer in the area surrounding development would have provided more relevant results with respect to energy development. Regardless, while this study was designed as a pre-development study, to my knowledge there has not been any follow up, a similar theme in the review of many studies that were putatively pre-development. Hopefully data from this earlier study can be used in the future to evaluate the effects of energy development, albeit without controls.

Five-years later, in the same study area, Irby et al. (1988) reviewed the status of energy development, created guidelines for the mitigation of energy development on wildlife, and provided recommendations for energy development. Irby et al. (1988) reiterated the results of Ihsle (1981) and Irby et al. (1988) and found no detectable response to low density oil and gas development, but emphasized that this earlier study was largely conducted during the pre- or early phases of energy development. Irby et al. (1988) recommended that continued monitoring occur throughout the increasing development phase, and recommended that mitigation should occur on the scale of entire winter ranges prior to development occurring. Irby also reviewed the guidelines used by Interagency Technical Committee 1987 guidelines for wildlife that BLM used for mule deer, which I provide in Appendix B for an important historic perspective. Importantly, however, despite the existence of best practices guidelines, Irby et al. (1988) note that BLM often violated these guidelines, and frequently issues exceptions to these stipulations for exploration and well drilling operations.

In southeastern Idaho, Merrill et al. (1994) studied the effects of mining developments on migration by mule deer between seasonal ranges in the Dry Ridge area. Using a combination of track surveys and a small number of radiocollared mule deer (n=5-7), they evaluated movements of mule deer around a phosphate mine located in a migratory corridor. The found avoidance of mining developments during migration, and recommended providing adequate forest cover, travel fences to direct movements away from development, and under or over-passes at specific locations to facilitate movements around human developments where required. They also caution that short term studies may fail to document effects in low snow winters, because migration was strongly influenced by snowfall.

In perhaps the first study on mitigating effects of highway caused habitat fragmentation on ungulates, Reed et al. (1975) studied the responses of mule deer approaching and attempting to cross a concrete highway underpass under I-70 in Colorado. The concrete underpass was not specifically designed for wildlife crossings, but observations suggested that it was being used by mule deer. Reed et al. (1975) used remote video camera's to record 4450 approaches by groups of mule deer that resulted in 1739 entrances/crossings (~40% success rate) of the structure. Sixty one percent of all individual mule deer that attempted to cross were successful, eventually. Animals that were unsuccessful at crossing were more vigilant and wary, reflecting the perceived risk of the crossing structure. This study laid a foundation for the development of the growing field of wildlife-highway mitigation (Clevenger et al. 2001,Clevenger and Waltho 2000). I do not review any additional studies of ungulate responses to roads, but summarize general results from the literature in the discussion.

3.5 Combined Studies on Mule Deer and Pronghorn

3.5.1 Sagebrush-Steppe

From 1988-91, Easterly (1991) conducted a study to examine the effects of energy development on both pronghorn and mule deer in the Rattlesnake hills of Wyoming, an area of sagebrush-steppe vegetation communities. Their study was in response to repeated violation by the BLM of the 1985 environmental impact statement

(EIS) on the Platte River Resource Area (which included the Rattlesnake hills) of their own policies regarding timing restrictions of energy development on crucial winter range for ungulates. Their policy, stated in the EIS, was that “no surface development will be allowed from Nov 15 through April 30 in critical pronghorn or mule deer winter range (BLM, 1985: 29). Despite this policy, BLM issued 18 permits in violation of this policy for drilling operations in crucial winter range between 1987 and 1991. Easterly et al. (1991) focused on testing whether violation of this policy was negatively affecting ungulates, but collected no pre-development data nor had any controls or comparison sites. Easterly et al. (1991) captured pronghorn and mule deer; they deployed 20 VHF collars, 175 neckbands, and ear tagged 28 males on pronghorn, and collared 29 mule deer all with VHF collars. They used a combination of radiotelemetry, and aerial and ground surveys to measure home range responses, densities, movements, and survival as a function of human development. Pronghorn densities were substantially lower closer to energy development and collared pronghorn avoided well sites during disturbance. Results for mule deer were more equivocal; densities of mule deer were similar close to and far from drilling activities, but mule deer were located farther from development during drilling, but not after, when they were the same distance as before development. This indicates some habituation response of mule deer to development. The authors attempted to draw some population consequences from their study, but were unable to. The prime limitation of this relatively well designed study was the lack of pre-development data on mule deer and pronghorn distribution in the region.

Medcraft and Clark (1986) studied the effects of reclamation of a 200ha coal mine on seasonal habitat use and diets over a 1 year period in northeastern Wyoming. The coal mine was reclaimed by a mix of native and non-native graminoids, forbs, and shrubs – only native shrubs were planted. Mule deer showed statistically significant selection for reclaimed lands more than expected based on availability, but pronghorn strongly avoided reclaimed lands. This difference was thought to be because mule deer selected non-native plants during summer (e.g., alfalfa), whereas pronghorn preferred native forbs which occurred at lower frequencies on reclaimed lands. Through behavioral observation, the authors also concluded that remaining mining structures such as fences and berms did not impede mule deer or pronghorn movements. The authors conclude by recommending reclamation of all disturbed sites with native species including graminoids, forbs and shrub species. To encourage shrub revegetation following development, Medcraft and Clark (1986) recommend concentrating shrub establishment efforts by patch seeding sites that are ecologically suitable such as draws, coulees, etc. Furthermore, cattle grazing of reclaimed lands should be minimized to allow re-vegetation and use by native ungulates.

Table 3. Review of scientific literature on the effects of energy development on Mule deer and Pronghorn, summarizing study authors, location, vegetation type, species (Aa- *Antilocapra* sp., Aas – *A. A. sonoranensis*, AlAl – *Alces alces*, Ce- *Cervus elaphus,* Oh- *O. hemionus*, Oc- *Ovis canadensis*), whether the study was peer reviewed or not, study area size, duration, development type, study design and sample size, general results and management recommendations.

Authors, location, Veg. type	**Spp.**	**Peer Review ?**	**Study Area Size, Duration**	**Development Type**	**Study design & size**	**General Results**	**Management Recommendations**
Armstrup 1978 MT-WY, grassland, sagebrush steppe	*Aa*	No	1036 km^2 and 2years	pre-development	Pre-development study, n=27 Ce; 75 Aa	General ecology study. Select sagebrush vegetation types in winter, fed for longer periods of time in winter, largely diurnal activity patterns, movements peaked during spring and fall, naturally shift between home ranges from year to year.	Sagebrush key for winter forage for pronghorn. Variation in winter range use makes long-term studies to identify critical habitat key.
Berger, 2004. Review	*Aa, Oh, Ce*	Yes	Review	Human habitat fragmentation, oil and gas.	Literature review of radio-telemetry studies	75% of the historic migration routes for elk, mule deer, and pronghorn in the Greater Yellowstone ecosystem have been lost due to human caused habitat fragmentation. Local risks to the trapper point migration corridor in the Upper Green River basin.	Creation of network of long-distance migration corridors required to conserve existing long distance migrations. Impacts greatest during spring and fall migrations.
Berger et al. 2005, 2006a, WY, sagebrush steppe	*Aa*	No	4000 km^2 and 2years		Comparative, radiotelemetry, n>50	First and second year progress reports on the effects of gas development on pronghorn in a control and treatment area in the Upper Green River basin.	Authors did not find pronghorn were avoiding developed areas at the current levels of development, but cautioned results are preliminary and ongoing and results of development should not be expected to occur instantly.
Berger et al. 2006b	*Aa*	Yes	~15,000 and 2years		Observational, archaeology, radio-telemetry, n=10	Compared migration routes identified with telemetry to archeological sites 6,000BP. Migration route has remained the same for at least 6000 years. Migration corridor has extremely narrow restrictions.	To protect critical migration routes, energy development needs to be restricted or removed to maintain long-term ecological processes. Migration seasons impacted most.

Table 3.

Authors, location, Veg. type	**Spp.**	**Peer Review ?**	**Study Area Size, Duration**	**Develop ment Type**	**Study design & size**	**General Results**	**Management Recommendations**
Bromley 1985 Review	*Aa, Oh, Ce*	No	N/A	Gas, oil, seismic exploration	Review, n=N/A	Ungulates avoid areas during construction phases, road building, drilling, seismic. Responses to established oil field difficult to determine because of few long-term studies with adequate temporal and spatial controls.	Timing and location restrictions required to avoid conflicts with ungulates, but this requires detailed knowledge of ungulate ecology. Called for large scale, long-term studies.
Bruns 1977 Alberta, grasslands	*Aa*	Yes	2500 km^2 and 0.3years	Roads	Observational, n=N/A	Avoidance of fences and highway; graded roads appeared to be selected by pronghorn, especially in deep snow winters.	Barbless fences not higher than 46 cm; farmers leave gates open (when unoccupied); improvement of winter microhabitat. Winter impacts greatest.
Easterly 1991 WY, shrubsteppe, grasslands	*Aa, Oh*	No	632 km^2 and 4years	Oil	Observational, n=20 Aa, 29 Oh	Densities within oil fields were consistently lower than outside. The 2 most heavily used oil fields were used less than expected, but others were used in proportion to their availability.	Recommend drilling on crucial winter range during summer months only when area is less critical to ungulates.
Freddy et al. 1986, CO, mountain	*Oh*	Yes	3 km^2, 2 years	Human disturbance	Comparative, radio-telemetry, n=7	Compared flight responses of mule deer to snowmobiles and hikers. Mule deer responded more to hikers than to snowmobiles.	Human activity restrictions required on winter ranges, winter greatest impact.
Gill et al. 2001 CO, Review	*Oh*	No	N/A	oil and gas, seismic	Review	Evaluated different hypotheses for mule deer declines in Colorado, with relevance to Montana. Causes for declines could be long-term habitat changes, competition with expanding elk populations, harvest, density dependence, disease.	Large-scale replicated management experiments are required to disentangle complex interactions to understand ungulate ecology. Recommended study designs are presented that are very relevant to energy development in Montana.

Table 3.

Authors, location, Veg. type	Spp.	Peer Review ?	Study Area Size, Duration	Development Type	Study design & size	General Results	Management Recommendations
Girard et al. 1985 ND, grassland	*Oh, Ov, Ce*	No	4068 km^2 and years	various oil/gas development	Review	Early-development literature review. 1% of landbase in ND study area impacted directly by energy development, unknown how much area lost indirectly.	Avoid wooded areas; reclamation; mitigation required. Emphasized importance of understanding effects of environmental toxins on wildlife.
Hayden-Wing Associates 1991 Review	*Aa, Oh, Ce*	No	N/A	Gas, oil, seismic exploration	Review, n=N/A	Ungulates respond the most during the construction phase, but are also displaced by human activities in the longterm, especially during winter and spring.	Recommend restriction of exploration on occupied winter range from Nov 15 to April 30 as a precautionary principle
Hiatt et al. 1982 WY, Mountain	*Ce, Oh*	No	101 km^2 and 0.25 years	Oil well	Comparative, n=	Both elk and mule deer shifted their ranges away from the well site. There was no evidence of avoidance of the access road by either species.	Minimal
Ihsle et al. 1981 MT, grasslands, pine breaks	*Oh*	No	2725 km^2 and 1.4 years	oil and gas, seismic	Observational, n=78	Impacts of gas and oil development difficult to assess because this was largely a pre-development study that has not been followed up.	None
Irby et al. 1988 MT, Review	*Oh*	No	2725 km^2 and years			No detectable response to low density oil and gas development, study largely conducted during the pre- or early phases of energy development.	Mitigation should occur on the scale of entire winter ranges prior to development occurring. Review the Interagency Technical Committee 1987 guidelines for wildlife (see Appendix B of this review).
Krausman, et al. 2004 AZ, Semi desert	*Aa, Oh*	Yes	km^2 and 2.25years	Military Operations	Experimental, n=4	No detectable difference between exposed/unexposed animals to either ambient or anthropogenic noise; no detectable difference in exposed/unexposed hearing thresholds	Reduce ground stimuli could help, but overall, drastic recovery measures beyond curtailing military activity are needed.

Table 3.

Authors, location, Veg. type	Spp.	Peer Review ?	Study Area Size, Duration	Development Type	Study design & size	General Results	Management Recommendations
Krausman, et al. 2004 AZ, Semi desert	*Aas*	Yes	377 km^2 and 3years	Military Operations	Observational, n=UNK	Habitat use proportional to availability, but appeared to favor habitats previously disturbed by military activities.	Continued monitoring required, ; multi-species responses; coordinated military/wildife use required, may benefit from fires from military use.
Landon et al. 2003 AZ, Semi desert	*Aas*	No	km^2 and 4years	Military Operations	Observational, n=31	Radiocollared pronghorn avoided high noise areas.	Potentially reduce overflights, study human disturbance in more detail.
Medcraft et al., 1986, WY, shrub steppe	*Oh*	Yes	200ha, 1 year	Mining	Observational, diet studies, N=?	Mining site reclaimed with a mix of native and non-native plants. Deer selected reclaimed mining lands more than unmined lands, preferring non-native plants during summer.	Reclaim all mining sites including graminoids and shrub species. Need to ensure cattle cannot access reclaimed lands or benefits lost. Focus on native species recommended.
Merrill et al. 1984, ID, Mountain	*Oh*	Yes	Unk, 5 years	Mining	Observational, tracks, telemetry, n = 5	Mining operations curtailed migratory movements of mule deer.	Travel corridors with sufficient cover should be considered to mitigate disturbance caused by mines.
Reed et al. 1975. CO, Mountain	*Oh*	Yes	Unk, 1 year	Roads	Observational, video N=4450	Videotaped mule deer responses to a concrete box underpass under I-70 in Colorado. Mule deer crossed underpass 40% of time at each attempt, 60% overall.	Underpasses can be useful to mitigate negative effects of habitat fragmentation and mortality caused by roads – first study of its kind.
Rost et el 1979 MT, pine breaks	*Oh, Ce*	Yes	km^2 and 2 years	roads	Observational, n=N/A	Deer and elk avoided roads, particularly areas within 200m of a road (based on abundance and density of fecal pellets).	Range improvement projects would benefit deer and elk more if they were located away from roads.

Table 3.

Authors, location, Veg. type	Spp.	Peer Review ?	Study Area Size, Duration	Development Type	Study design & size	General Results	Management Recommendations
Sawyer et al. 2002 WY, shrubsteppe, grassland	*Aa, Oh*	Yes	798 km^2 and 4years	pre-development	Pre-development, n=171 Oh; 35 Aa	Mule deer populations traveled 64-161 km yearly; pronghorn traveled 161-241 km.	Energy development has the potential to impact travel corridors for pronghorn and mule deer.
Sawyer et al. 2004 WY, sagebrush, grasslands	*Oh*	Yes	798, 3 years	Gas, seismic	Review, n=N/A	Review of the potential effects of oil and natural gas development on Pronghorn in Wyoming.	Recommends approach to determine the effects of energy development on wildlife that emphasizes long-term, well thought out management experiments between control and treatment areas.
Sawyer et al. 2005 WY, sagebrush, grasslands	*Oh*	No	~800 km^2 and 4 years	natural gas development	BACI, n=69	Mule deer in the treatment area decreased 46% in 4 years under high densities of roads and well sites (see Table 5 below).	Higher densities of wellpads will negate the potential effectiveness of timing restrictions on drilling activities.
Sawyer et al. 2005 WY, sagebrush, grasslands	*Oh, Aa*	Yes	15,000 km^2 and 3 years	roads, housing developments, mineral exploration	Observational, n=171 Oh; 34 Aa	Mule deer and pronghorn migrated 20-158 km and 116-258 km respectively, between seasonal ranges. A number of significant bottlenecks were observed on migration routes.	Migration routes are important components of mule deer and pronghorn ranges. Fences, road networks, and increased human disturbance associated with energy and housing developments influences the effectiveness of mule deer and pronghorn migration routes.
Sawyer et al. 2006 WY, sagebrush, grasslands	*Oh*	Yes	~800 km^2 and 6 years	natural gas development	Comparative, n=77	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.	Higher densities of wellpads will negate the potential effectiveness of timing restrictions on drilling activities.

Table 3.

Authors, location, Veg. type	Spp.	Peer Review ?	Study Area Size, Duration	Development Type	Study design & size	General Results	Management Recommendations
Stephenson et al. 1996 CO, grasslands, pine breaks	*Oh*	Yes	1040 km^2 and 3 years	Military Operations	Comparative, n=71	Mule deer in areas with active military operations (or previous activity) consistently had larger home ranges than those in areas with no activity. 40% of does shifted their home ranges and after military operations started in an area.	
White et al. 2007. MT/WY, mountain, sagebrush-steppe ecosystem	*Aa*	Yes	~750 km^2, 6 years	Tourism development	Observational, radiotelemetry, n=44	Yellowstone pronghorn were partially migratory, with 70% migrating 15-50km away to 4 different summer ranges from the same winter range. Individuals showed high fidelity to summer ranges, but 20% adopted a variable migration strategy from year to year. Migration though to be condition dependent, influenced by weather, climate and density. Migration corridor has extremely narrow restrictions.	Protection of critical migration corridors for pronghorn especially important because of threats to migration corridors in the study area and considering large scale loss of migration in the Greater Yellowstone ecosystem.

3.6 Bighorn Sheep (Ovis canadensis)

No published studies were found on the effects of energy development on bighorn sheep. Most resource conflicts between development and bighorn sheep appear to be cause by mining, not energy development *per se*. A number of studies have been conducted on the effects of human development and recreation. Therefore, I focus on reviewing the effects of mining and energy development in general on bighorn sheep.

In general, bighorn sheep avoided habitats disturbed by human activities (hiking, etc) in Arizona (Etchberger et al. 1989), roads and highway traffic in Rocky Mountain National Park (Keller and Bender 2007), construction activities in Nevada (Leslie and Douglas 1980), human activities including vehicles, mountain bikers and hikers in Canyonlands National Park (Papouchis et al. 2001) and to human hikers or humans with dogs in Alberta (MacArthur et al. 1982). Sheep in Canyonlands avoided areas within ~500m of human development, a loss of access to 15% of high quality habitat. Dall sheep (*Ovis dalli nelsonii*) also showed responses to human activities, especially females, who rested less and foraged more when disturbed by humans. One of the most common forms of human disturbance investigated was the effects of aircraft overflights (helicopter, fixed-wing) on bighorn sheep. Studies on the effects of aircraft on bighorn and Dall sheep (Bleich 1990, Stockwell 1991, Frid 2003) as well as Mountain Goats (*Oreamnos oreamnos*) consistently show an impact on bighorn sheep at distances from 250-750 meters straightline distance (above ground level) for sheep, and even greater distances for mountain goats (Cote 1996), who responded to aerial disturbance at distances of up to 2000m. Based on these studies, clear recommendations to avoid overflights on mountain sheep and goat habitat were presented by all authors.

In terms of bighorn sheep response to mining development, results were equivocal. Jansen et al. (2006, 2007) showed behavioral differences in and out of a copper mine in Arizona, where sheep fed less and bedded more within the mine site, controlling for the effects of age-class. However, despite these minor differences, Jansen et al. (2006, 2007) concluded that bighorn sheep may readily habituate to mining activity, and that reclamation was needed following mining activities. In contrast, Oehler et al. (2007) found that at a mine in the semi-desert mountains of California, Desert bighorn were negatively impacted by mining activities, suffering reduced forage quality, increased signs of disturbance during summer, and potentially important population effects. They concluded that where water was limiting for desert bighorns, mines should avoid areas near permanent water sources for bighorn sheep. In Alberta, a large open-pit mine was reclaimed following coal extraction using planting of native plants combined with extensive post-mining soil grading, seeding, and fertilization (MacCallum and Geist 1992). Sites were successfully reclaimed with native legume species (e.g., Astragalus spp. Smyth 1997), and forage biomass increased for sheep dramatically from 1700kg/ha on native grasslands to 4100kg/ha on reclaimed lands. bighorn sheep apparently responded at the population level, with higher local densities, increased horn growth, and lower lungworm counts. Therefore, sheep seem able to respond to reclamation very well.

3.7 Moose

There have been few studies of the impacts of energy development or human activity on moose in the regions considered as part of this literature review. In a classic study of the effects of human disturbance on moose, Altmann (1958) studied the effects of moose sex, age, reproductive status and season on the flight response of moose to human observers. Flight response measures the perceived risk of ungulates to disturbance; as flight response increases, i.e., ungulate flee an approaching human at a greater distance, the perceived risk imposed by the disturbance are thought to also increase. Altmann (1956) found that female moose with calves at heel fled human disturbance at a farther distance than other age-classes, and that moose fled sooner during the hunting season because of increased risk of human caused mortality during this period. Flight responses varied seasonally, declining the most during the rut, and for moose females with <1 month old neonate calves at birthing sites. This study laid the foundation for research investigating flight response of ungulates, and provides an important foundation for understanding the potential population implications of development.

In the Kakwa River valley of Alberta's forested foothills Horesji (1979) conducted a brief observational study using snow track surveys of ungulate crossings of a seismic line before, during, and after the construction phase in winter. Four species, in order of track abundance, were recorded; Moose, Elk, Mule Deer and Woodland Caribou. Despite very small sample sizes for all species (n=26 total track crossings), Horesji (1979) concluded that Moose avoided the seismic line only during construction, use before and after did not appear affected, though inferences are weak at best because of the limited duration, scope, and sample size. Conclusions about other species could not be drawn because of low numbers of samples.

In the only other study of human activities on moose I review, Berger (2007) showed that the responses of moose to human activity were complex and mediated by predation risk by grizzly bears in Grand Teton National Park, WY. Over a nine-year study, Berger (2007) documented selection by moose for distance to roads within the park, and showed that as the density of grizzly bears increased over this 9 year study, moose increased their selection for areas for calving close to roads within the study area. Because grizzly bears are an important predator of neonatal moose calves, and because grizzly bears avoided human activity, Berger (2007) argues that moose were selecting areas near human activity because grizzly bears avoided human activity. Thus, human caused refugia in predation risk by a natural predator emerged as an indirect effect of human activity on roads in this National Park ecosystem. This phenomenon, whereby human activity repels carnivores such as wolves and grizzly bears, thereby providing are refuge for ungulate prey, has been documented in other systems in North America. In Banff National Park, wolf avoidance of human activity created a refuge for elk, which benefited from increased adult and calf survival in areas where wolves avoided people. This refuge effect lead to a trophic cascade on vegetation, beavers, and other competitors with elk inside the refuge (Hebblewhite et al. 2005).

These studies emphasize the important consequences of human development on ungulates will often be mediated through the indirect effects of changes of the distribution of predators in response to roads and human activity. In Montana, where natural predators such as coyotes, wolves, and mountain lions coexist with ungulate species, the responses of ungulates to energy development will often be mediated by human-induced changes to carnivore distribution and habitat use.

3.8 Woodland Caribou (*Rangifer tarandus tarandus*)

In this review I focus my efforts on studies on the effects of energy development on Boreal woodland caribou (*Rangifer tarandus tarandus*). I exclude, in the large, effects of energy development on Barrenground caribou (*Rangifer tarandus grantii*), focusing here mainly on the effects of development on Alberta woodland caribou populations. Energy impacts on migratory arctic caribou have been summarized by numerous authors, and focus on the effects of development of the Alaska north slope oil reserves (National Research Council 2003,Cronin et al. 2000,Cronin et al. 1998), although more recent efforts focus on impacts in the Canadian Arctic (Johnson et al. 2005). While I do not review them in detail in the text, I summarize Arctic caribou herd studies in Table 4.

Research on the effects of energy development on woodland caribou has progressed largely in these three phases; 1) studies on the effects of construction or seismic activities during exploration, 2) studies on altered ecosystem dynamics that influence caribou population viability, and 3) regional, cumulative effects assessment approaches that address caribou population viability at large regional scales. In the discussion I draw parallels between caribou research in Alberta and ungulate-energy impacts in the lower-48 states, where research is largely being conducted at the first or second step.

Studies that examined the impacts of well-site development or seismic exploration confirmed the negative impacts of these phases of energy development on caribou. Initial development restrictions in Alberta were similar to those put in place in the 1970's and 1980's in Montana for wildlife (e.g., Appendix B) – namely that it was the disturbance during development which posed the most significant impact on caribou. This formed the basis for early regulations designed to minimize the timing of development overlap with key ‘calving seasons’ and late winter seasons. In effect, this policy is a formulation of the hypothesis that the main impacts of development are behavioral only, and that through avoidance of key behavioral periods, development impacts can be minimized. This policy was tested in a series of experimental and modeling studies. Bradshaw et al. (1997, 1998) showed the negative impacts of disturbance caused by seismic exploration explosions increased caribou movement rates, habitat shifts, and reduced feeding times. These behavioral changes resulted in potential loss of body mass and reduced reproduction, linking avoidance to population declines. Yet the magnitude of observed impacts in these simulation studies was less than the rate of declines of some caribou herds, suggesting the next round of studies that investigated dynamics at the level of the individual caribou herd.

A series of studies across the boreal forest now confirm that amongst the main reason caribou populations are declining through large-scale changes to predator-prey dynamics as a result of forestry and oil and gas development (Alberta woodland caribou recovery team2005, COSEWIC2002). Historically, caribou coexisted at large spatial scales with moose and wolves by adopting a spatial separation strategy whereby they selected large contiguous patches of habitats unsuitable for wolves and their primary prey, such as peatland bogs or large patches of old growth conifers (James et al. 2004). Increased forestry produces early-seral stands with abundant food for primary prey, moose, which increase in population density with increasing forestry. This in turn increases wolf population densities (Fuller et al. 2003), which, when they exceed a density of approximately 7 wolves/1000km^2 exert enough secondary predation influence on caribou to reduce survival rates and drive population declines (Stuart-Smith et al. 1997, McLoughlin et al. 2003, Alberta woodland caribou recovery team 2005, James and Stuart-Smith 2000). Oil and gas development exacerbates changes from forestry by providing high densities of oil and gas seismic exploration lines upon which wolves have been shown to have the following negative ecological impacts. Wolves travel at higher speeds on seismic lines (James et al. 2004), which increases kill rates on large ungulate prey species (Mckenzie 2006, Webb et al. In Press), and increases overlap of wolves and caribou (Neufeld 2006). As a result, caribou show strong avoidance of human development near roads and seismic lines, as well as well sites (Dyer et al.

2001, 2002). Dyer et al. (2001) documented maximum caribou avoidance of areas 250m from roads and seismic lines and 1000m from wells, which, when extrapolated to the entire study area, impacted from 22-48% of available caribou habitats with potential road avoidance effects. Dyer et al.'s (2000) results presented the first clues that human development impacts were operating cumulatively and at large spatial scales.

During the next phase, scientists began studying population dynamics of impacted caribou herds across Alberta, confirming that the majority were declining (Mcloughlin et al. 2003, Alberta woodland caribou recovery team 2005) due to the mechanisms described above (Mcloughlin et al. 2005). Both empirical (McLoughlin et al. 2005) and modeling research at this stage confirmed the grim predictions of the cumulative effects of landscape change on caribou (Lessard et al. 2005,Weclaw and Hudson 2004, Sorenson et al. 2008) – aggressive and dramatic changes to the status quo energy development policy and/or aggressive interim measures such as landscape restoration, core protected areas, and large-scale energy development restrictions may be necessary to recover this federally threatened species (Alberta woodland caribou recovery team 2005). Unfortunately, efforts to restore seismic lines using experimental line blocking experiments failed to achieve any measureable reduction in travel by wolves, and Neufeld (2006) concluded that seismic line restoration at the scale necessary to reduce predation risk on caribou was unfeasible.

Finally, cumulative effects assessment at large scales confirms the grim picture facing caribou conservation in the face of energy development in Alberta. Using data from the previously mentioned studies, Schneider et al. (2003) developed cumulative effects assessment scenario's for caribou herds in Alberta, and showed that even under optimistic scenario's in development rates, which that have been exceeded within the 5 years since Schneider et al. (2003), available caribou habitat would decline from 42% of the study area (59,000km^2) at present to around 6% within 100 years. Empirical cumulative effects models also confirm the dire straits caribou face. By comparing population growth rates of caribou populations against the total amount of industrial development within caribou ranges and the total amount of caribou ranges burned by fire, a management model was developed that predicted expected caribou population growth rate simply as a function of % industrial development and % area burned

(Sorenson et al. 2008, Fig. 10). **Therefore, from a simple management perspective, the key variables after decades of research boiled down to the amount of habitat lost, which disproves the policy hypothesis that energy development can be mitigated with timing or seasonal restrictions, and also refutes the hypothesis that incremental continued energy development is consistent with caribou persistence.**

Today, caribou are listed as a threatened species both federally and provincially, with over 60% of identified herds in Canada declining because of some form of industrial human development (Alberta woodland caribou recovery team 2005). Drastic recovery actions are being proposed, and the federal government is presently developing critical habitat designation that will undoubtedly result in recommendations for restrictions on the amount of industrial development allowed within caribou ranges (Alberta woodland caribou recovery team 2005). In summary, these studies emphasize several key points; 1) short-term disturbances from energy development are not necessarily the most significant population level impacts; 2) by the time population-level impacts were detected, it was almost too late to recover many populations, or the level of restoration activities required are not feasible; 3) it is the amount of habitat disturbed by humans, not habitat fragmentation effects per se, that drove caribou population declines, 4) the sample size is effectively the population of caribou both for statistical, biological, and planning reasons, 5) cumulative impacts were not always evident from individual studies, and required scaling up to regional scales.

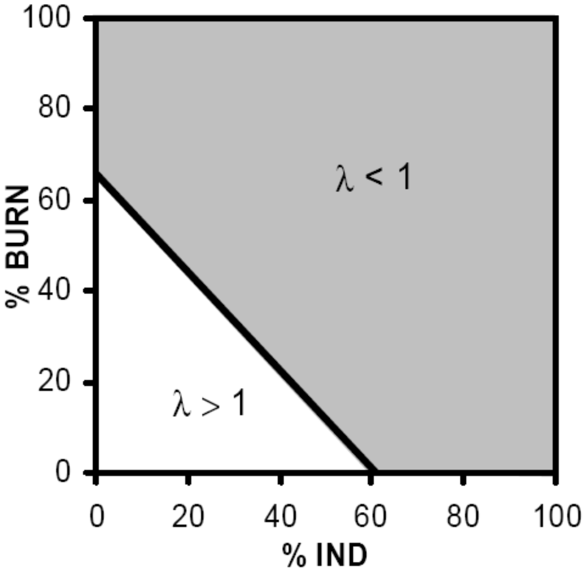


Fig. 10. Meta-analysis model for woodland caribou population growth rate as a function of the % of the boreal caribou range that was burned and the % of the caribou range converted to non-habitat through industrial development. The regression model was developed using n=6 woodland caribou population ranges across a 20,000km^2 area in Northern Alberta, and is described by $\lambda = 1.191 - (0.314 * IND) - (0.291 * BURN)$ ($R^2 = 0.96$, $n = 6$, $P = 0.008$) [Sorenson et al. 2008].

Table 4. Review of scientific literature on the effects of energy development on Moose, Bighorn Sheep, and Caribou, summarizing study authors, location, vegetation type, species (AlAl – *Alces alces* (Moose), Oc- *Ovis canadensis*, Rtc – *Rangifer tarandus caribou* (Newfoundland subspecies), Rtg – *Rangifer tarandus grantii* (Barrenground caribou), and Rtt- *Rangifer tarandus taranuds* (Woodland caribou), whether the study was peer reviewed or not, study area size, duration, development type, study design and sample size, general results and management recommendations.

Authors, location, Veg. type	Spp.	Peer Rev-iew?	Study Area Size, Duration	Develop-ment Type	Sample design & size	General Results	Management Recommendations
Moose							
Altmann 1958 WY, various	*AlAl*	Yes	Unk, 3years	Human recreation / hunting	Observational	Hunting pressure increased flight response, and cows with calves were easily disturbed. Flight distance declines during rut, and with newborn calves. Both sexes became habituated to some degree to human disturbance.	Effects of human disturbance on moose could be great enough to affect population dynamics.
Berger 2007, WY Mountains	*AlAl*	Yes	~500km^2, 9 years	Human activities	Comparative radiotelemetry, n= 192	Evaluated effects of predation by grizzly bears on selection by moose for roads. 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.
Horesji 1981 Alberta, foothills	*AlAl, Oh, Rtt, Ce*	No	and 0.15years	Seismic exploration	Comparative (BDA), n=26		Moose only species with enough data, crossed less during than before/after exploration

Table 4. Bighorn Sheep

Authors, location, Veg. type	Spp.	Peer Rev-iew?	Study Area Size, Duration	Develop-ment Type	Sample design & size	General Results	Management Recommendations
Bighorn Sheep							
Etchberger et al. 2007, AZ, semi desert	*Oc*	Yes	250km^2, 2 years	Human disturbance	Observational	Compared landscape covariates between areas currently occupied by bighorn sheep in the Coronado forest vs. areas unoccupied. Habitats used by bighorn sheep have less human disturbance, and higher forage biomass.	Fire is important and restoration of fire could enhance sheep habitat. Reducing human activity in the abandoned areas could enhance restoration of this population.
Frid (2003)	*Oc*	Yes	Unk, 1 year	Helicopter & aircraft disturbance	Experimental, n=56 experimental overflights	Aircraft approaches that were more direct (relative to the sheep) were more likely to cause sheep to flee or disrupt resting, and latency to respond was longer. Sheep had a 10% chance of fleeing when aircraft were as close as 750m, and a 10% chance of disrupting rest as far as 1.5km away.	Recommend avoiding known sheep ranges by as much as 1.5 km based on disturbance to resting behavior instead of fleeing behavior – the most costly response.
Jansen et al. (2006, 2007), AZ, semi-desert	*Oc*	Yes	Unk, 2 years	Mining disturbance	Observational, radiotelemetry, n=12	Minor differences in sheep behavior inside and outside the mining area; Sheep spent more time feeding and less bedding inside the mine.	Sheep appeared to habituate to mining activity rapidly. Emphasis placed on restoration, especially in desert or semi-desert environments.
Keller & Bender (2007), CO, mountain	*Oc*	Yes	~500km^2, 2 years	Human recreational disturbance, roads	Observational, behavioral observation	The number of sheep groups visiting a key mineral lick adjacent to a road declined as human disturbance increased, and the time and number of attempts required by bighorn to reach Sheep Lakes was positively related to the number of vehicles and people present at Sheep Lakes.	Negative effects of road and human avoidance may affect population dynamics. Recommended seasonal human use restrictions to maintain sheep populations..

Table 4. Bighorn Sheep

Authors, location, Veg. type	Spp.	Peer Rev-iew?	Study Area Size, Duration	Develop-ment Type	Sample design & size	General Results	Management Recommendations
Leslie & Douglas (1980), NV, semi-desert	*Oc*	Yes	Unk, 1 year	Human disturbance, Construction	Observational, telemetry, n=17	Construction caused a significant shift in use of artificial water sources by 9 of 17 female marked sheep. Productivity during construction did not depart from the long-term population mean; however, lamb survival may have been affected.	Particular care should be given to water sources for bighorn sheep during development, habituation may ameliorate long-term negative effects to some degree, but population declines could occur.
Loehr et al. (2005), YT, Subarctic mountains	*Oc dalli*	Yes	Unk, 1 year	Human disturbance by hikers	Observational, n =35	Females rested less and foraged more under human disturbance and were more vigilant, but not males.	None.
MacArthur & Geist (1982), AB, Mountain	*Oc*	Yes	Unk, 2 years	Human disturbance, hikers and dogs	Observational, heart rate monitors, n=5	Cardiac and behavioral responses were greatest to humans and humans with dogs or approached sheep from over a ridge. Reactions to road traffic were minimal, and no reactions to helicopters or fixed-wing aircraft were observed at distances exceeding 400 m from sheep.	Responses to disturbance were detected using HR telemetry that were not evident from behavioral cues alone.
MacCallum & Geist (1992), AB, Mountain	*Oc*	Yes	Unk, 1 year	Mining disturbance & restoration	Observational	Sheep seasonal movements were similar to those found on native ranges. They used the reclaimed areas as winter range and for the mineral licks exposed during mining. Two thirds of all sightings were confined to 1.3 km of reclaimed grassland; its average productivity (4190 kg/ha) exceeded native ranges (1700 kg/ha). Infestation with lungworms was moderate. Lamb production and survival were high.	Design criteria should be: feeding areas should be dry and lie within 300 m of escape terrain, which should have a slope of 40% and contain at least three benches. Rock piles should be placed on grazing areas. Mineral licks, a vital welfare factor, already existed within the high walls created by strip mining.

Table 4. Bighorn Sheep

Authors, location, Veg. type	Spp.	Peer Review?	Study Area Size, Duration	Develop-ment Type	Sample design & size	General Results	Management Recommendations
Oehler et al. (2005), CA, semi-desert, mountain	*Oc*	No	Unk, 3 years	Mining disturbance	Comparative, treated vs. treated area, radiotelemetry n = 19	Size of annual home ranges, composition of diet, and ratios of young to adult females did not differ between female sheep inhabiting mined and nonmined areas. Nonmined areas had higher forage biomass than mined sites, and in spring, female sheep had lower forage quality. Sheep were reliant on water adjacent to the mine which influenced results.	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), UT, semi-desert	*Oc*	Yes	Unk, 2 years	Human disturbance, hiking	Comparative, behavioral avoidance	Hikers caused the most severe responses in desert bighorn sheep (animals fled in 61% of encounters), followed by vehicles (17% fled) and mountain bikers (6% fled). Bighorn sheep were avoided around 39% farther from roads (490 +/- 19 m vs. 354 +/- 36 m) than in the low-use area.	We recommend managers confine hikers to designated trails during spring lambing and the autumn rut in desert bighorn sheep habitat.
Smyth (1997)	*Oc*	Yes	Unk, 2 years	Mining, reclamation	Observational	Survival and success of high elevation legumes varied as a function of drought stress, root exposure by frost-heaving, and elevation.	Native Astragalus spp. species can be used for mining reclamation.
Stockwell (1991)	*Oc*	Yes	Unk, 1 year	Helicopter & aircraft disturbance	Observational	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.	Restrictions on helicopter overflights are recommended for National Parks, recommended >500m linear distance between sheep and aircraft.

Table 4. Cont' Caribou

Authors, location, Veg. type	Spp.	Peer Rev-iew?	Study Area Size, Duration	Develop-ment Type	Sample design & size	General Results	Management Recommendations
Caribou							
Alberta Caribou Recovery Team 2005, AB, boreal forest and foothills	*Rtt*	No	>100,000 km^2, endangered species recovery plan	Oil, gas, seismic, forestry, linear development	Review	Caribou populations declining across the province because of cumulative effects of energy development	Aggressive energy development restrictions and restoration activities required including reduced logging, road removal, rehabilitation of seismic lines, protected areas with no development, predator and ungulate control
Bradsaw et al. 1998, AB, boreal	*Rtt*	Yes	20,000 km^2 and 5years	Petroleum exploration	Modeling, n=N/A	Potential loss of mass and increased energy costs	Model may serve as a template for future research
Bradsaw et al. 1997, AB, boreal	*Rtt*	Yes	20,000 km^2 and 1years	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
Cameron et al. 2005, Alaska, arctic	*Rtg*	Yes	8,000 km^2 and 22years	Petroleum development	Review	calving caribou avoided roads and caribou exposed to petroleum development may have consumed less forage during the calving period.	Assessments of cumulative effects of petroleum development on caribou must incorporate the complex interactions with a variable natural environment.
Cronin et al. 1998, 2000 Alaska, arctic	*Rtg*	Yes	17,000 km^2 and 20years	Oil fields, roads, well pads, infrastructure	Review	Herd-level impacts of the Prudhoe Bay oil fields are not apparent on the Central Arctic caribou herd.	Resource extraction and wildlife populations can be compatible when managed properly.

Table 4. Cont' Caribou

Authors, location, Veg. type	Spp.	Peer Rev-iew?	Study Area Size, Duration	Develop-ment Type	Sample design & size	General Results	Management Recommendations
Dyer et al. 2000, AB, boreal	*Rtt*	Yes	6,000 km^2 and 1years	roads, seismic lines, pipelines	Observational, n=36	Seismic lines were semipermeable 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.
Dyer et al. 2001, AB, boreal	*Rtt*	Yes	6,000 km^2 and 1years	new/old well pads; roads; seismic	Observational, n=36	traffic indices inconclusive; disturbance sites showed bias towards habitat type;	Fewer human-used/created corridors; less industrial development; effects greatest during summer.
Haskell et al. 2006, Alaska, arctic	*Rtg*	Yes	700 km^2 and 3years	Oil fields, roads, well pads	Observational, n=up to 12,000	Caribou are able to habituate to active oilfield infrastructure during and after the calving period depending on the timing of the spring snowmelt. Groups with calves were on average distributed farther from infrastructure than groups without calves.	Development of calving period-specific mitigation measures that are effective and flexible is important because annual rehabituation is correlated with timing of spring snowmelt.
James et al. 2005	*Rtt*	Yes	20,000 km^2, 4 years	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.
James & Stuart-Smith 2000, AB, boreal	*Rtt*	Yes	20,000 km^2 and 7years	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.
Johnson et al. 2006, NWT, arctic	*Rtg*	Yes	190,000 km^2 and 5years	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.

Table 4. Cont' Caribou

Authors, location, Veg. type	Spp.	Peer Rev-iew?	Study Area Size, Duration	Develop-ment Type	Sample design & size	General Results	Management Recommendations
Joly et al. 2006, Alaska, arctic	*Rtg*	Yes	Ukn and 23 years	Oil field, roads, infrastructure	review	Calving caribou gradually abandoned the oilfield with a drop in abundance by at least 72% in spite of the fact that the total herd increased 4-5 fold.	
Mahoney et al. 2002, Newfoundland, boreal	*Rtc*	Yes	12,000 km^2 and 7 years	Hydroelectric development	Observational before, during, after development, n=51	Hydroelectric development caused a disruption of the migration timing during construction and longer-term diminished use of the range surrounding the project site.	Long-term studies of individually marked animals can aid in environmental assessments for migratory animals.
McLoughlin et al. 2005, AB, boreal	*Rtt*	Yes	Unk and 11 years		Observational, n=195	Uplands present caribou with higher than expected levels of predation risk. Caribou should max selection of peatlands.	Linking fitness measures to multivariate resource selection will enable us to ask questions of evolutionary ecology once restricted to only the finest ecological scales.
McLoughlin et al. 2003, AB, boreal	*Rtt*	Yes	Ukn and 10 years	human development	Observational, n=332	Wolf predation most common cause of death. Calf production 75-95%, mean annual recruitment was ~20 calves per 100 cows. 4 of 6 herds declining.	New land-use guidelines to promote caribou conservation
Nellemann et al. 2001, Norway, arctic	*Rtt*	Yes	2900 km^2 and 12 years	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, Norway, arctic	*Rtt*	Yes	1350 km^2 and 10 years	Hydroelectric development	Observational, 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.

Table 4. Cont' Caribou

Authors, location, Veg. type	Spp.	Peer Rev-iew?	Study Area Size, Duration	Develop-ment Type	Sample design & size	General Results	Management Recommendations
Neufeld 2006, Boreal forest, foothills	*Rtt*	Yes	~3500 km^2, 3 years	Oil and gas, seismic lines	Observational & Experimental	Experimental rehabilitation of seismic lines using logging equipment failed to elicit any reduced use of cutlines by wolves. Spatial overlap between wolves and caribou was enhanced by seismic lines.	Managers should not assume long-term impacts of oil and gas development can be restored or reclaimed. Cutline restoration will require large investment in funding to be successful. Better approach to reduce footprint initially.
Noel et al. 2004, Alaska, arctic	*Rtg*	Yes	225 km^2 and 23 years	Oilfield development, roads	Observational, n=up to 1,259	Caribou density after road construction was not lower < 1km of roads than pre-road. # calving caribou in the study area has declined since road construction. Distribution of caribou was not strongly influence by presence of the road.	
O'Brien et al. 2006, Manitoba, Boreal forest	*Rtc*	Yes	900 km^2 and 4 years	forestry and road development	Modeling, n=11	Strong relationship between large clusters of high-quality winter habitat patches and winter GPS telemetry locations from two herds in Manitoba	Results highlight importance of accounting for the spatial configuration of habitat on the landscape and the intervening land cover types when assessing range quality for woodland caribou.
Schaefer & Mahoney 2007, boreal	*Rtc*	Yes	2700 km^2 and 9 years	clearcut logging	Observational,68 years, n=237 animal-years	Females avoided cutovers and maintained an average of 9.2km from active cutovers, males had no response to clearcuts.	Long-term investigations are needed to enhance our capacity to evaluate anthropogenic habitat changes.
Schneider et al. 2003, AB, boreal	*Rtt*	Yes	59,000 km^2 and model dependent	energy and forestry development	Modeling	Model predicts caribou habitat availability will decline from present levels of 43 to 6% in 40 years.	Substantial improvement in ecological outcomes can be achieved through alternative management scenarios while still maintaining a sustainable flow of economic benefits.

Table 4. Cont' Caribou

Authors, location, Veg. type	Spp.	Peer Rev-iew?	Study Area Size, Duration	Develop-ment Type	Sample design & size	General Results	Management Recommendations
Sorenson et al. 2008, Boreal forest	*Rtt*	Yes (In Press)	50,000 km^2, 10 years	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 (~8,000km^2) scale.
Stuart-Smith et al. 1997, AB, boreal	*Rtt*	Yes	20,000 km^2 and 4years	n/a	Observational, n=65	Adult survival averaged 0.88, calf survival was 18 calves/100 cows. Lambda was 0.92. Lower calf survival and smaller home ranges in landscape with less fen patches and a higher proportion of upland.	n/a
Vors et al. 2007, Ontario, boreal	*Rtc*	Yes	n/a and 15years	roads, utility corridors, mines, pits and quarries, trails, rail lines	Modeling	Forest cutovers were the best predictor of caribou occupancy with a tolerance threshold of 13 km to nearest cutover and a time lag of 2 decades between disturbance by cutting and caribou extirpation.	Buffers should be incorporated around habitat and range of occupancy should be monitored.
Weclaw & Hudson 2004, AB, boreal	*Rtt*	Yes	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.
Weir et al. 2007, Newfoundland, boreal	*Rtc*	Yes	195 km^2 and 6years	gold mine development	Observational, before, during development, n=~8000	Caribou avoided areas within 4km of the site in most seasons. Group size and number decreases as mine activity progressed in late winter, pre-calving and calving seasons.	Importance of evaluating the year-round impact of human-induced environmental change.

4.0 DISCUSSION

Wildlife managers, environmental planners, wildlife consultants, and energy developers who had hoped that this review would provide clear recommendations for approaches to mitigate the effects of energy development on wildlife populations are likely to be disappointed. A number of reviews have already been conducted on the impacts of energy development on wildlife, nearly 10% of all studies reviewed in this effort were previously conducted literature reviews on exactly the topic covered here (e.g., Hayden-Wing 1991,Berger 2004, Bromley 1985). If the preponderance of reviews on the subject is any indication, then there is a large demand for information about the effects of energy development on wildlife such as ungulates. Many of these previous reviews provide information about mitigation strategies for small-scale effects of energy disturbance on ungulate behavior, yet most conclude their reviews admonishing managers to conduct more long-term, population-oriented studies. Unfortunately, my conclusions from reviewing the literature are that, at least for ungulates, there still remains no clear or effective management recommendations that will definitively mitigate the impacts of energy development on ungulate ***populations*** (emphasis added) in the habitats present in eastern and central Montana.

I draw this conclusion for the following main reasons. First, to date, there has not been one rigorously conducted study (e.g., a replicated experiment) of the effects of energy development on ungulates for a ***sufficient duration*** of both study and energy impact to be able to draw firm conclusions about the population impacts of development on ungulates species present in eastern and central Montana. The average duration of studies was very short (2.5 years) when compared to the lifespan of ungulates that may live for over 20 years. Few studies actually measured adult female survival, and *not one* study reported population growth rate for pronghorn, mule deer, elk or bighorn (caribou being the exception). The studies that did measure adult female survival failed to show any impact of energy development by and large, but were only conducted for a short time period, consistent with the low statistical power (Gerrodette 1987) expected for species with high and constant adult survival rates (Gaillard et al. 2000). For long-lived species such as ungulates, impacts of changes to the environment may take up to decades to manifest through cohort effects, compensatory reproduction by adult females, resilience in the adult age-cohort, and because ungulates in general have extremely high and constant adult survival, even despite large-scale changes in environmental conditions (Albon et al. 2000, Coulson et al. 2005, Festa-Bianchet et al. 2003, Gordon et al. 2004). Following from Gaillard et al. (2000) and Eberhardt (2002), energy impacts are expected to manifested first on the least sensitive, but most variable population vital rates such as calf survival and recruitment, not the most important, but least variable adult survival rates. In fact, ungulate life-history in general makes it extremely difficult, or almost impossible, to determine the effects of energy development on population parameters within a short 2-3 year study. Recent recommendations of reviews of ungulate demography studies suggest that a minimum of 50-60 marked adult female ungulates monitored over at least 5-years (Gordon et al. 2003, 2004) are required to gain a mechanistic understanding of changes in adult survival rates linked to environmental changes such as energy development. While population level surveys are capable of picking up important changes (Sawyer et al. 2005), without detailed demographic data, mechanisms driving changes will be cause for speculation. Thus, long-term changes in the way in which agencies and industry engage in research on energy impacts on wildlife need to occur.

My second major reason for why I conclude that impacts of energy development on populations are not possible at this point in time is because of the timing of many studies during early development phases. Following from the arguments above that the effects of energy development may take years to manifest on long-lived ungulates, most studies reviewed were conducted either during the pre- or first 1-5 years of development. This does not give populations long-enough to equilibrate to development and loss of habitat. A major additional problem with studying impacts of development only early during development is that density of development is confounded with duration of development – again confusing clear cause and effect relationships because of the period of equilibration that might be required for long-lived ungulates. An extreme example of this is the study by Van Dyke and Klein (1996) who investigated the impacts of the first oil well constructed in a nearly undeveloped area on elk behavior with a hope to estimate population-level impacts. At such low densities, population level responses for a large bodied mobile herbivore would not be expected to occur because, as this review confirmed, ungulates can habituate to responses at low enough development thresholds.

Regardless of these conclusions about the **population-level** impacts of energy development, the review provides some conclusions about the behavior-level impacts of energy development on ungulate species that will be useful to planners at the site-level of the individual wellsite or road alignment. Many of these behavior-level impacts were already summarized by previous literature reviews (Bromley 1985, Hayden-Wing 1991, National Research Council 2003,Girard and Stotts 1986). However, the real question is whether such small-scale mitigations, referred to as 'death by a thousand cuts' (e.g., Lustig 2002) are useful to scale up to population level responses.

At the small scale, most ungulates displayed behavioral responses that weakly to strongly avoided energy development activities during the development phase (seismic blasting, road construction, mining construction, forest operations, and well drilling), although responses varied. Pronghorn, elk, and mule deer generally showed the strongest avoidance responses, in that order, while bighorn sheep were equivocal in their responses to the construction phases of energy development (Table 2, 3, 4). Seasonal impacts were variable, and occurred year round during winter ranges, calving ranges, migratory corridors, and summer ranges. Early studies tended to focus on effects of development on winter ranges, and restrictions on 'crucial' winter ranges are still enforced as small-scale mitigation measures to minimize the impacts of energy development on wildlife. However, recent studies seem to show increasing effects of energy development on spring calving ranges of ungulates, during summer, and especially in migration corridors (discussed below). This may reflect the growing appreciation within the literature of the importance of summer nutrition to ungulate demography (Cook et al. 2004, Parker et al. 2005). Regardless, clear recommendations for timing restrictions on spring calving ranges and critical winter ranges were echoed by a majority of studies for all species, especially elk, mule deer and pronghorn. Therefore, timing restrictions already developed to minimize the effects of development on ungulates during these key times should probably be kept in place and continued to be monitored for effectiveness (see below).

Also at the small-scale, energy development had impacts on ungulates through the effects of roads and the amount of development, which I review next.

4.1 Effects of Roads

Roads are one of the most pervasive impacts of human development on natural landscapes (Forman and Alexander 1998), and by far, their greatest impact lies in the indirect effects of habitat fragmentation and avoidance by wildlife. By current estimates of wildlife-road relationships, the lower continental USA has around 10-20% of available habitats impacted to some degree or another by wildlife. Impacts of roads on wildlife are not all or nothing, and extend in some continuous function of distance from roads that differ in the overall avoidance buffer size across species (Forman and Alexander 1998). In a preliminary attempt to extract information about ungulate responses to roads associated with energy development for this review, I summarized those studies that presented analyses of the effects of distance to energy development (road, wellsite) on measures of ungulate resource selection.

It is important to note that this zone of influence does not imply 100% avoidance (Schneider et al. 2003,Harron 2007), yet from the information presented in many of the studies reviewed, actual effective reductions in habitat use was not presented. For example, Dyer et al. (2001) found on average 40% reduction within 100m of a seismic line, and declines up to 250m away. Powell (2003) reported 73% reductions in use within 2000m of energy development, but other studies did not usually present enough information. In the 8 or so studies that did report some sort of avoidance effect of roads that was quantifiable, the average ‘zone’ of influence extended approximately 1000m from both roads and wells, though responses varied within seasons and between species (Table 5). In general, ungulates avoided roads more during the summer months than during winter, when they were often constrained to be closer to roads because of increased snow depths, etc. Regardless, even considering an effective loss of habitat of 50% within this zone of avoidance and a modest buffer size of 500m reveals that 10% of a study area can be effectively lost due to indirect avoidance of roads under optimistic assumptions. The role that overlap between well sites and roads plays on the effects of habitat loss due to avoidance is important and should be investigated in detail in the kinds of habitats present in eastern Montana because of the importance of spatial configuration of habitats in determining road impacts (Rowland et al. 2000,Frair 2005).

Table 5. Summary of ungulate studies showing avoidance of roads and well sites, averaging results across seasons and habitat types.

		Avoidance Buffer (m)	
Author	Species	Roads	Wells
Gillan (1981)	Elk	1200	500
Edge (1982)	Elk	500	1000
Rost (1988)	Elk	200	
Dyer et al. (2000)	Caribou	250	1000
Sawyer et al. (2005)	Mule deer	2700	
Powell (1988)	Elk	2000	2000
Frair (2005)	Elk	200	
Ward (1986)	Elk	2000	
	Average	1131	1125

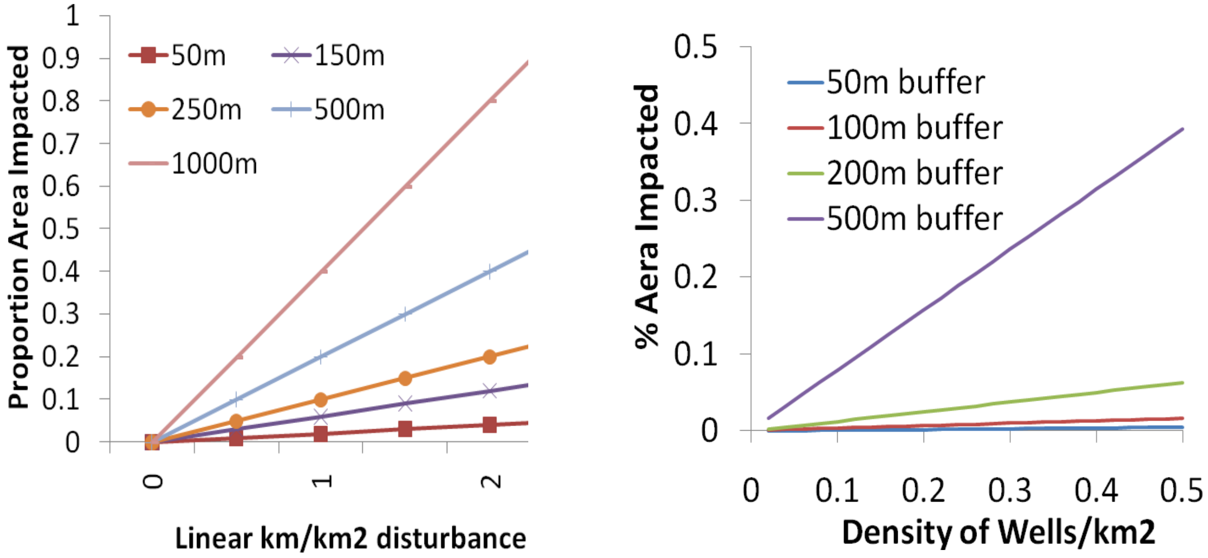


Fig.11. Simple algebraic models for the effects of increasing wildlife buffer avoidance size as a function of linear disturbance and the density of wells, assuming no overlap of buffers of disturbances – an unlikely biological scenario. However, these are useful as guidelines because the actual effects of overlap will be landscape specific, although they will tend to cause the relationships to decline asymptotically to a lower % total area impacted. Studies of the effects of road and wellsite distribution in grassland and sage-steppe habitats are needed.

4.2 Amount of Development

I extracted the density of oil and gas development from studies where possible. Unfortunately, from the n=70 or so studies that investigated the direct impacts of development on wildlife, only a handful (n=12) presented sufficient information to be able to estimate either the density of wellsites or the density of linear disturbance (road, seismic Table 6). Undoubtedly, with additional research and perhaps change detection remote sensing studies, densities of development during the actual study could be backcast for meta-analyses (see below). For these 12 studies, I attempted a simple univariate meta-analysis of development densities for studies that reported a significant statistical effect of energy development on some response variable against those studies with no effect. I present these results only as preliminary results of univariate meta-analyses as an example what additional investment in meta-analyses of existing data could yield. Caveats of this simple summary are many; scale effects of study area size and determination were not accounted for, study duration was also not included, and sample size of the original study, and its variance, were not considered. Regardless, studies that showed a significant impact of energy development tended to have a much higher density of both wellsites and roads, consistent with ecological theory (Forman 1998) and results of individual studies. Somewhere between 0.1 and 0.4 wells/km^2 and between 0.18 and 1.05 linear km/km^2 of development significant impacts started to manifest on ungulate species including mule deer, pronghorn and elk. Additional research is necessary, however, to disentangle effects of sample size, study duration, and impact type (behavioral, habitat effect, population) on the relationship between development density and impacts. I review formal meta-analyses below as a next step in energy-wildlife research needs.

Table 6. Summary of density of energy development disturbance in terms of density of active wellsites/km2 and linear kilometers of pipelines, seismic lines and roads / km2 from studies where such information was reported. Despite small sample sizes of studies that reported densities, ambiguities in definition of study areas, and simplification of impacts to a binary variable, densities of disturbance appears to be related to the impact of energy development.

Study	Density of Wells/km^2	Linear km of roads / pipelines / seismic / km^2	Significant Impact?[3]
Knight et al. (1981) – Ce[1]	0.088	N/A	NO
Olson (1981) – Ce	N/A	0.15	NO
Rowland et al. (2000) - Ce	N/A	0.62	YES
Sawyer (2002) - Aa, Oh	N/A	0.62	YES
Bennington (1981) – Ce	0.20	N/A	NO
Van Dyke & Klein (1996) - Ce	<0.001	N/A	NO
Sawyer (2005a, b)[2] – Oh	1.01	1.36	YES
Berger (2005, 2006)[2] – Aa	0.25	0.20	NO
Frair et al. (2005, 2007) – Ce	0.20	1.6	YES
Easterly et al. (1991) – Aa	0.27	N/A	YES
Ihlse et al. (1981) – Oh	0.003	N/A	NO
<u>Summary Statistics</u>	<u>Mean (n)</u>	<u>Mean (n)</u>	
Significant Impact – Yes	0.49 (3)	1.05 (4)	
Significant Impact – No	0.10 (4)	0.18 (2)	

1- Species are as in Tables 3-4.
2- These two sets of studies occur in approximately the same area but defined different study area sizes based on species life history.
3- Significant impact is a simple binary variable confirming whether statistically significant effects of energy development were detected on key response variables.

4.3 Limitations

4.3.1 Experimental Design

Despite the useful information provided in the reviewed studies for developing preliminary guidelines to guide energy development to minimize impacts on ungulate species, my review revealed several major problems with previous studies including 1) poor experimental design including lack of replication, controls and pseudoreplication, 2) limitations of scale, 3) and poor execution and timing with respect to energy development. Gill (2001) provide an excellent review of experimental designs for large scale adaptive management experiments required to tease apart reasons for mule deer declines in Colorado, many of which would be suitable designs for determining the effects of energy development on wildlife. I briefly touch on experimental design issues here (Krebs1989, Underwood1997, Gill 2001, Williams et al. 2002).

From a traditional scientific paradigm, reliable knowledge is generated through carefully thought out and planned replicated experiments that are designed to test a specific hypothesis, then revised once that hypothesis is accepted or rejected and a new experiment designed. In ecological systems, researchers and managers often do not have the luxury of conducting one at a time experiments just to test one hypothesis; instead, the philosophy of multiple working hypotheses is adopted (Chamberlain 1890, Burnham and Anderson 1998). Regardless, experimental controls in a replicated system provide the strongest inference.

Unfortunately, of the reviewed studies, the vast majority employed an observational or correlational-design (47%), where responses within one population to human disturbance are regressed against some covariate such as distance to roads (Fig 14). While useful, it is difficult to determine cause-and-effect relationships or mechanisms in such studies. Many observational studies were gray-literature reports designed as a mitigation strategy to permit development (which I discuss below). Reviewing these studies especially gives the impression of the following common scenario (summarized succinctly by Lustig (2002);

1) A permit for drilling a well is requested in an area defined as critical winter range for an ungulate.
2) The permit is granted with stipulations that minimize putative negative effects by minimizing temporal risks during critical times (calving).
3) Either because of violation of the stipulations, or in fact as an additional stipulation, a study is commissioned to investigate the effects of energy development activity X on wildlife species Y.
4) The correlative study is often designed hastily, with inadequate resources, sample size, temporal or spatial scope, without pre-development data, nor any commitment to monitoring beyond the intended life of the development phase.

In the course of my review, I have come to the conclusion that wildlife biologists, as a profession, are failing to live up to professional standards and guidelines of their chosen professional organization, The Wildlife Society, by agreeing to participate in these poorly-designed studies that are merely aimed at appeasing the small-scale regulatory process. The huge number of animals captured and handled (>2000), their capture-related mortality, the huge financial investments made by energy development companies, and the huge investment in personnel time do not weigh favorably against the meager conclusions about the effects of energy development on ungulate populations. Figure 6 reinforces the impression that the bulk of studies of wildlife-energy relationships have been reactive, driven by trends in oil production, not part of any pro-active adaptive management program. At the least, I hope this review convinces some of the need for better designed studies of energy-wildlife impacts.

Comparative studies provide stronger inference, for example, between the same population before and after without a control, and were employed in 19% of studies reviewed. The lack of a control makes it difficult to determine whether changes before and after development were due to the development, or some unmeasured covariate, for example, snow or weather. For this reason, comparative studies, while an improvement, will be unable to provide strong inference about the effects of development on populations.

The third kind of study design, experimental, is when effects of development on ungulates after development occurred are compared between a control and developed population, without before data on the development population (Fig. 14). Eighteen percent of studies reviewed used this design. This example was common when pre-development data were not available, usually because the study was designed as an afterthought to development or to allow violation of a stipulation for drilling during exploration. The problem with experimental comparisons of this kind is that without data on the pre-development population, it is difficult to conclude that differences between treatments were not due to some additional, unmeasured variable present in the treatment population. This is a serious concern where experimental units cannot be randomized and where replication is difficult; both conditions are prevalent in all wildlife-energy studies. Randomization is so difficult to achieve at the level of assigning treatments that I do not discuss it further here; but randomization of the assignment of control populations could conceivably occur, and randomization of animal's radiocollared within studies should also occur as possible. A good example of a strong experimental comparison amongst the studies reviewed were the Upper Green River Basin studies on pronghorn by Berger (2004, 2006) and colleagues. The study used a treatment and control group, but had limited data pre-development, although as energy development increases in the study area, the first year of the study may very well serve as pre-development conditions. If so, this would make this study design very powerful.

The most powerful design, that of a before-after-control-impact design (BACI, Underwood 1997) was employed in 18% of studies reviewed. BACI designs are amongst the most powerful experimental designs because effects of development are compared between a treatment and control simultaneously both before and after development. This design alleviates difficulties with previous designs controlling for spatial and temporal confounding. The best example of this BACI design in all the studies reviewed are epitomized by the studies on the Sublette mule deer herd because they had extensive pre-development data on mule deer survival and habitat use, compared to 5-years and running of post-development data between a control and treatment population (Sawyer et al. 2005, 2006). Priority should be given to maintaining funding for this study especially because of its relevance, large spatial scale (see below), and strong design.

Despite these compliments, a central tenant of experimental design, replication, was absent from all reviewed studies. Not one study was replicated at the level of treatment. Obviously replication at the spatial scale here is difficult to achieve, but future efforts should be made to initiate additional studies in areas with and without development to serve as meta-replicates; that is, replicates at the scale of meta-analyses between populations.

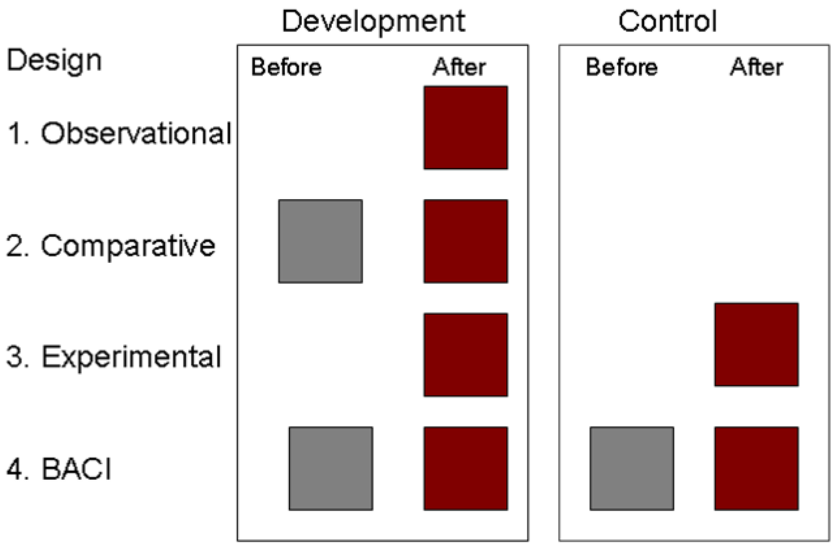


Fig. 13. Common experimental designs for studying the impacts of energy development on wildlife in increasing order of scientific rigor (Underwood 1996). 1) Observational studies simply observe relationships between a parameter and the level of development. 2) Comparative studies compare the effects of development before and after on a parameter without contemporaneous control. 3) Experimental designs compare a control and treatment group post development. 4) In a Before-After-Control Impact (BACI) design, 4 paired sites are used to compare effects of development on a parameter before development in both a control and pre-treatment site, and after development in both a control and post-development site. Note in this schematic, there is no replication.

4.3.2 Spatial Scale

A difficult problem in ecology is how to scale-up from short-term small scale behavioral decisions of animals to long-term landscape scale population and distributional responses. The difficulty in scaling up is why so few of the studies that showed short-term responses were able to measure or demonstrate these long-term or population level responses. A second scaling problem is presented by Berger et al. (2007) when discussing issues of spatial scale and habitat fragmentation, both of which are totally dependent on each other (Dale et al. 2000, Turner et al. 2001). Quantifying habitat fragmentation metrics will be completely determined by the study area size, and for this reason, many authors recommend conducting multi-scale analyses of the effects of habitat fragmentation on wildlife species (Turner et al. 2001, Harrison and Bruna 1999).

In many of the studies I reviewed, there was a third scaling problem – that of extrapolating responses. This occurred where the effects of a local point source disturbance (wellsite) was assessed at the population or at the home range scale, and results extrapolated well beyond the development densities under which the response was studied. For example, Van Dyke and Klein (1996) document the responses of elk home ranges to installation of a single well in a hitherto undeveloped grassland ecosystem in north central Montana. This was the first well to be installed in a 200km^2 area, an extremely low well density. The authors basically found few impacts of the well installation on elk home range use, and no lasting impacts on behavior or habitat use. The results of this study have been extrapolated to other wells across Montana, yet the validity of extrapolating the finding of no significant impacts to areas of higher well density, for example, is questionable. This emphasizes the need to establish thresholds for development or broad, regional scale cumulative impact assessments as the density of well sites and development increases.

Finally, there was often a scale-mismatch between the spatial scale of the study in question, most often focused on some crucial winter range, and the spatial scale of the population under investigation. Assuming the goal of an impact study is to assess the impacts of a particular development on a population, unless the study area represents the annual range occupied by the ungulate population, it will become difficult to evaluate whether the changes in the population are occurring because of energy development on the winter range, or because of undocumented changes occurring elsewhere in the populations range, for example.

One potential solution to the issue of how to determine the appropriate study scale is to use the spatial scale of migration as a guideline in migratory populations. Berger (2004) reviews long-distance migration throughout western North America and worldwide, and migration distances for ungulates in western North America are presented in Table 7. While not all populations are migratory, the reported degree of partial migration ranged from 45 to 100%. Considering the one-way migration distances as a buffer of any particular energy development suggests that the correct spatial scale to consider evaluating the effects of energy development could range from 1500km^2 for bighorn sheep to nearly 19,000km^2 for pronghorn. Notably, when compared to the scale of reported study areas in this review, these rough guidelines are much greater than reported by studies attempting to address development impacts in the literature. Surely, study area specific guidelines should be developed once migratory movements are determined, but these guidelines emphasize the large spatial scale required to understand population-level impacts.

Table 7. Summary of one-way migration distances recorded in selected reviewed studies that were mainly summarized by Berger (2004). Assuming the goal of the energy-wildlife impact study is to make inferences to the population, the study area size and spatial scale that impacts should be assessed over can be calculated as the spatial scale of migration.

Study	Species	Distance (km)	SE	% Migrant	n
Sawyer et al. 2005	Pronghorn	177	2	95	34 pronghorn
Sawyer et al. 2005	Mule deer	84	5.1	100	158 deer
White et al. 2007	Pronghorn	35	---	70%	44 pronghorn
Berger 2004	Pronghorn	137	12.1	N/A	7 pops.
Berger 2004	Mule deer	73	5.2	N/A	16 pops.
Berger 2004	Elk	93	7.1	N/A	7 pops.
Berger 2004	Bighorn	39	4.1	N/A	5 pops.
Berger 2004	Caribou	71	7.9	N/A	4 pops.
Berger 2004	Moose	85	4.3	N/A	13 pops.
Hebblewhite et al. 2006	Elk	55	8.9	45%	60 elk

Summaries

Species	Study area size required to contain migratory movements
Elk	8,464 km^2
Mule Deer	5,423 km^2
Pronghorn	18,769 km^2
Bighorn	1,521 km^2
Caribou	5,041 km^2

4.4 Potential Toxicological Impacts

Girard and Stotts (1986) are the only studies in this review that specifically mention the potential negative effects of H_2S (hydrogen sulphide) on wildlife species. Yet recent studies have demonstrated the potential negative effects of H_2S emitted from sour gas wells (natural gas fields) on domestic cattle in Alberta (Waldner et al. 2001a,b, Scott et al. 2003a), although results are equivocal at this point (Scott et al. 2003b).

Moreover, there is increasing interest in investigating the human health consequences of sour gas emissions from natural gas wells, with recent studies potentially linking H_2S emissions to human health and increased risk of cancer, cardiovascular disease, and endocrine dysfunction (Saadat et al. 2006, Roth and Goodwin 2000, Waldner et al. 1998) and even real estate prices. A recent government sponsored study in Alberta emphasizes that H_2S should be considered a broad-spectrum toxicant, and that repeated exposure may result in cumulative health impacts on the brain, lung, and heart (Roth and Goodwin 2000), although the report calls for increased medical research to establish cause-and-effect relationships. Regardless of the uncertainty regarding the effects of emissions from energy development on wildlife, it is surprising that no studies have investigated the effects of increased exposure to toxic chemicals emitted from oil and gas wells. Collaboration with ecotoxicologists is recommended as a future area of potentially important research

4.5 Conceptual Approach for Understanding the Effects of Energy Development on Wildlife

One of the conclusions from this review is that the effects of energy development on ungulate species will be manifested through changes in the ecological communities of species, including humans, in which they exist. As such, impacts of energy development on ungulates can be classified into direct impacts and indirect impacts. Distinguishing between *direct* effects and *indirect* effects and between species is critical to understanding the mechanisms of energy development impacts on ungulates, and to providing effective mitigation strategies to ensure the sustainability of energy development. In community ecology, *direct effects* between species (e.g., human, energy development, and elk) occur when there are no intermediary species between two interacting species, for example, through direct mortality associated with energy development (road kills, poaching, destruction of nests, etc Estes et al. 2004). Most direct effects are classified as either predation (energy development directly kills wildlife species) or habitat destruction, where the population size of wildlife is directly reduced because of the reduction in available forage as a result of development (area of habitat directly lost by well sites, roads, compressor stations, etc).

In contrast, *indirect effects* of energy development are where impacts on a wildlife species are mediated by an intermediate species. As an example of indirect effects, Fig. 12 illustrates the indirect effect of energy development on sage grouse and kit foxes (*Vulpes macrotis*) mediated by human caused changes in the densities of important predators in this terrestrial grassland community, such as coyotes (*Canis latrans*) or red-tailed hawks (*Buteo jamaicensis*, e.g., Fig. 12). In this example, raptors have increased predation rates on sage grouse because of increased perching habitat near attractive sink habitat near road ditches for sage grouse (Aldridge and Boyce 2007, Fletcher et al. 2003). Similarly, coyote populations increase following human development because of habitats associated with human development supports higher densities of small mammals, causing increased predation by coyotes on kit foxes (Haight et al. 2002a).

Effects of energy development will likely go far beyond direct impacts purely based on community ecology theory (Estes et al. 2004). Recent reviews have reminded ecologists that direct effects are but a fraction of the potential species interactions possible in even a simple food-web (Estes et al. 2004, Bascompte et al. 2005). For example, in Fig. 13, the total number of direct interactions (such as direct mortality) between the six species is 30, whereas the number of indirect species interactions is 1,920! (see Estes et al. (2004) for calculations). This emphasizes that wildlife managers should be very concerned about indirect effects of energy development in Montana and

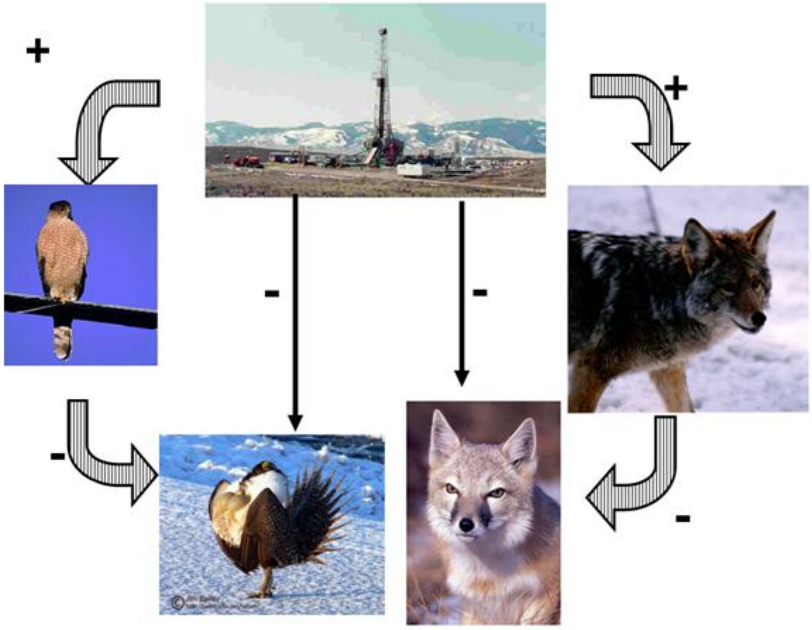


Fig. 12. Conceptual trophic food web illustrating direct (solid lines) and indirect effects (dashed). Interaction strength of one trophic level on another is shown by the thickness of the arrow, and the magnitude of the effect by the sign whether positive (+) or negative (-). In this example, energy development benefits predators such as raptors and coyotes with additional foraging habitat, causing stronger negative indirect effects than direct effects on vulnerable Sage grouse and Kit fox.

design effective strategies to mitigate them.

Indirect effects of energy development can also arise because of behavioural changes by ungulates in response to energy development such as avoidance of roads and wellsites. These results have been corroborated across systems and at larger scales in ungulates confirming the importance of indirect behavioural effects, such as the avoidance of predation risk and human disturbance (i.e., energy development) by ungulates on ecosystem dynamics (Fortin et al. 2005, Rothley 2001, Hebblewhite et al. 2005).

Despite the theoretical support for the importance of indirect effects, a cursory review of the literature on the subject of impacts of energy on wildlife reveals a seemingly myopic focus of mitigation strategies on reducing direct effects such as road mortality and direct habitat destruction (BLM 2003a,b). A renewed focus on the indirect effects of energy development mediated by community level changes in species will underscore the influences of indirect effects in the cumulative impacts of energy development. In this literature review, I will test the hypothesis that indirect effects are more prevalent than direct effects of energy on ungulate species. If indirect effects are more common than direct effects, I expect to find evidence that the impacts of energy development on wildlife are mediated by changes in community dynamics of other species (i.e., increased human access during hunting season, increased coyote abundance, etc.,) or through behavioural changes of ungulates in response to energy development.

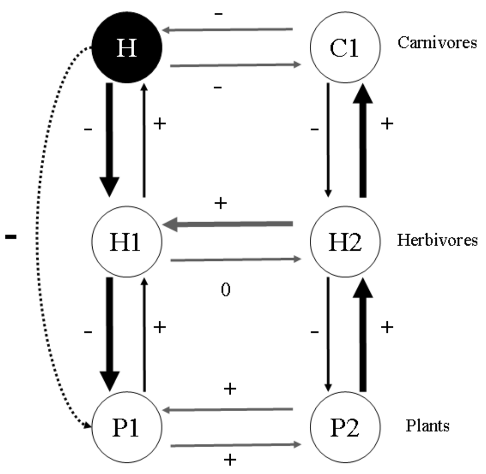


Fig.14 . Conceptual diagram illustrating the importance of indirect species interactions in understanding the effects of energy development on wildlife. A conceptual three-trophic level food web illustrating direct (solid) and indirect (dashed) interactions between human energy development, carnivores, herbivores, and plants is shown. Predation and other direct interactions (competition, etc) are illustrated by black and gray lines, respectively. Fourteen of 30 direct species interactions are shown, whereas only 1 of 1920 potential indirect effects are shown, in this case, the indirect effects of human energy development on plant species 1 mediated via changes in the abundance of herbivore 1.

4.6 Recommendations for Future Energy Development Impact Studies on Ungulates in Eastern Central Montana

4.6.1 Meta Analyses

Meta-analysis is the most rigorous form of synthesis and review in the scientific literature, and is used to combine results of analyses into one synthetic framework to test broad hypotheses in science (Hobbs and Hilborn 2006, Osenberg et al. 1997, Hedges et al. 1999, Arnqvist and Wooster 1995). Great advances have been made in the recent decade in ecology in particular by synthesizing results of single studies to test broad ecological hypotheses, for example about the effects of predators on ecosystems (e.g., Schmitz et al. 2000, Shurin et al. 2002). In its simplest form, each study becomes one replicate in the meta-analysis, thus, meta-analysis is extremely useful for augmenting statistical power in hypothesis testing because multiple small-scale studies are combined effectively as a series of replicated studies.

Meta-analysis of the effects of energy development is the next logical step to take to quantify the impacts of energy development on ungulates following standard meta-analysis. Three basic pieces of information from published studies are required to conduct meta-analysis; the mean treatment effect, the sample size (n), and the standard deviation in the response (Schmitz et al. 2000, Gurevitch and Hedges 1999, Arnqvist and Wooster 1995). For advanced meta-analysis, extraction of more detailed information from each study area; such as road density, well density, date of initiation of development, etc., could help elucidate responses of wildlife to energy development in formal meta-analyses. For each study, the mean values are extracted for response variables from the experimental (energy development) treatment ($\overline{X}_j^E$ where E is experimental) and the control treatment ($\overline{X}_j^C$ where C is control). The difference between two treatments for the j^{th} study, or the effect size, is calculated by the difference of the means following:

$$E_j = \overline{X}_j^E - \overline{X}_j^C \qquad \text{(equation 1).}$$

While effect size is an intuitive metric, it is difficult to compare across studies and different response variables because of scaling issues (Hedges et al. 1999); how does one compare the magnitude of the difference in survival which may be small, especially with ungulates (e.g., 0.1) with the magnitude of flight response between studies? A better measure is the log response ratio, L_j, for several reasons (see Oseberg 1999 for details). Meta-analyses uses the response-ratio to estimate the effect size of the energy development between the treatment and control (Hedges et al. 1999,Gurevitch and Hedges 1999) following:

$$L_j = \log(\overline{X}_j^E / \overline{X}_j^C) \qquad \text{(equation 2)}$$

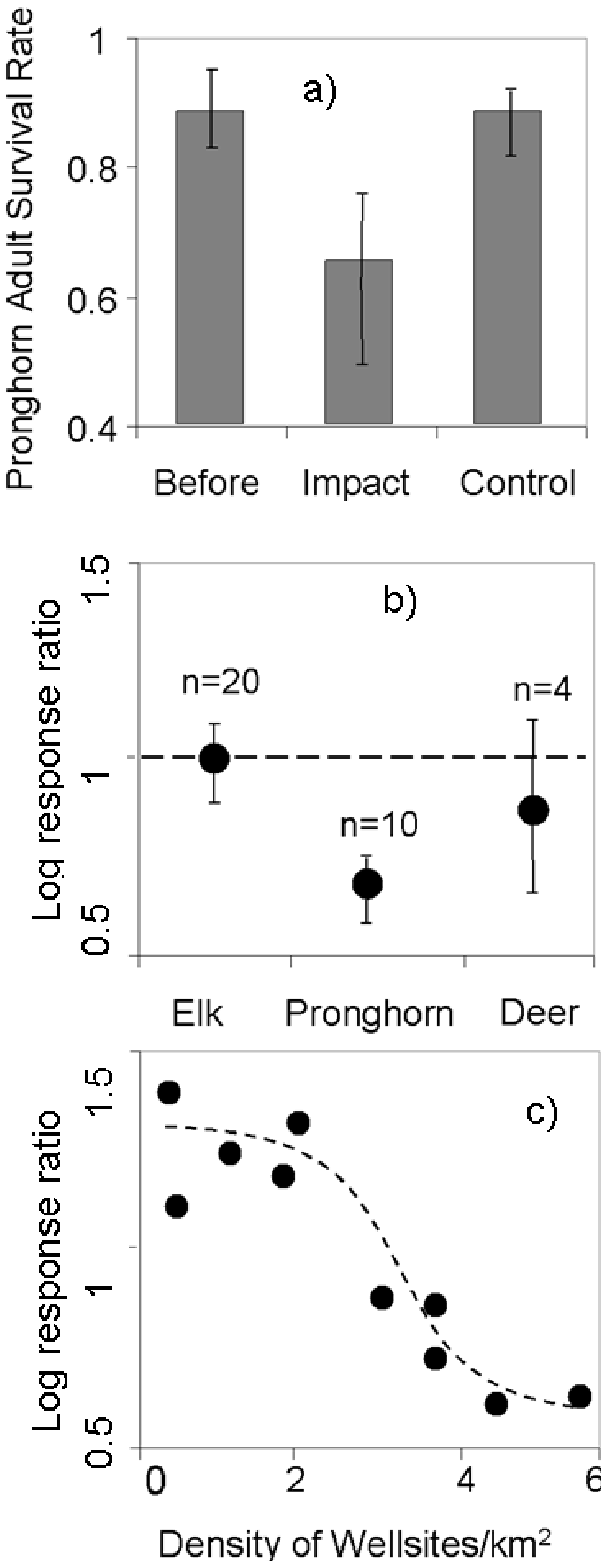
Response ratios less than 1 represent the hypothesis that energy development has a negative impact on the response variable, and vice versa for values greater than 1. For parameters that may be changing over the duration of energy development (i.e., as the ungulate population equilibrates to the new disturbance, lost habitat, changed predator-prey regimes, etc), it is important to consider trends over time in the response ratio (Osenberg et al. 1997). If effects are not constant, it is important to report the trend in effects. Variance in log response ratios are calculated following Hedges et al. (1999). As an example, I illustrate meta-analysis using a hypothetical example of a review of the effects of energy development on survival of adult female pronghorn, elk and mule deer (Box 1). Meta-analysis of the literature reviewed in this study would help formalize the tantalizing syntheses presented in Tables 4 and 5 that are suggestive of thresholds in responses of wildlife to the amount of energy development, and calculate averaged responses of wildlife avoidance of roads associated with human development.

Box 1. Meta-analysis illustrated with a hypothetical example of a review of the effect of energy development on survival rates of adult female pronghorn, elk and mule deer.

The first figure (a) shows a well designed, replicated (see section 4.4) study on the effects of energy development on survival of adult pronghorn in a before-after-control impact design (BACI). The magnitude of the difference in survival between the control/before treatment and the impacted treatment (0.85-0.63 = 0.22) is termed the **effect size** of the treatment (see equation 1 above), in this case, energy development. Sample size is the number of collared animals, and the wider confidence intervals in the impact represent the common situation of greater variation in the treatment response, emphasizing the importance of sufficient sample size.

In the second figure (b) **the log response ratio** (see equation 2) from a number of different studies on ungulate survival have been summarized. Response ratio's greater than zero represent a net positive impact of energy development and values less than zero represent a net negative impact of the treatment across studies (n is now # of studies). Effect sizes are standardized with respect to the sample size and variance of the data in figure (a) for each study. Deer illustrate the case where too few studies were likely conducted to draw concrete conclusions.

In the final figure (c) the response ratio is now regressed against some consistent spatial measure of habitat fragmentation (in this case density of wellsites/km^2) to test for thresholds in the cumulative effects of development on, in this example, ungulate survival rates. In this example, if the standardized effect size, Z, corresponding to the maximum decrease in ungulate survival was -0.2 (which could correspond to a survival rate of 0.75), then the threshold for wellsite density would be approximately 3 wells/km^2.



4.6.2 Habitat-linked cumulative effects assessment

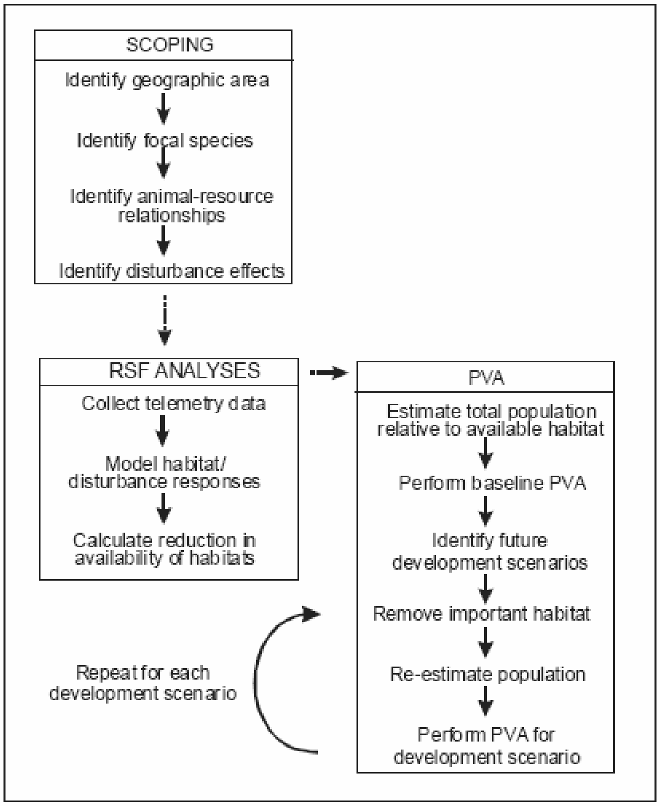


Fig.15. From Johnson & Boyce (2005). Analytical framework for the development of habitat linked PVA analysis to assess the impact of wildlife within a population undergoing energy development.

Johnson et al. (2005) and Johnson and Boyce (2005) provide a template for the assessment of regional cumulative environmental effects on 4 species of wildlife in the central Canadian Arctic in a region of rapidly increasing diamond mine (and oil) exploration and development. The area in which regional development impacts were assessed was a huge area, over a 190,000km^2 area for four wildlife species; caribou, grizzly bears, wolves and wolverines. Lack of adequately sized spatial or temporal controls, the sheer size and difficulty of collecting wildlife data in the study area, and the availability of existing wildlife telemetry data lent themselves to a habitat-modeling based assessment of development impacts. Under the assumption that resource selection ultimately dictates population demography of wildlife species (Boyce and McDonald 1999, Manly et al. 2002), Johnson et al. (2005) developed habitat-based population viability model based on Resource Selection Functions (RSF). Briefly, once focal species are identified, RSF models that quantify the relationship to human activity are developed. Next, potential habitat disturbance caused by energy development is modeled as a function of future landscape scenarios (Johnson et al. 2005, Schneider et al. 2003), and the area of effective habitat loss is measured using the RSF model. The assumption that habitat quality predicted by RSF models relate to population sizes has been recently supported in several studies on caribou (Seip et al. 2007) and grizzly bears (Ciarniello et al. 2007, Boyce and Waller 2003). Then, given a reduction in habitat quality revealed by the RSF model, a habitat-linked population viability model (Haight et al. 2006, Carroll et al. 2003) can be developed to evaluate the effects of competing energy development scenarios on wildlife. I agree with recent authors (Carroll and Miquelle 2006, Morris and Doak 2002) that caution against treating the predictions of such PVA as quantitative. Rather, recent studies show that habitat-linked PVA provides relative comparisons between alternate development scenarios. As such, habitat linked PVAs could be a useful modeling tool for adaptive management (see below). The limitations of this approach is the fundamentally correlative nature within one population undergoing energy development; whether relationships hold over future development patterns need to be assessed through continued monitoring, and whether the link between resource selection and fitness is necessarily held in wildlife populations impacted by human development (e.g., Mcloughlin et al. 2005) needs to be tested. A comparative study design between populations that are and are not impacted by development would be a stronger approach.

4.6.3 Large-scale, replicated experimental tests of the impact of energy development on ungulates.

As this literature review summarizes above, the current state of knowledge about the impacts of energy development on wildlife is woefully lacking on several critical fronts. First, knowledge of the effects of long-term impacts on wildlife population parameters is essentially absent – study duration averaged <3 years, an inadequate timeframe to assess the impacts of energy development on long-lived ungulates. With dozens of short-lived studies, we literally have almost no idea what population responses to energy development will be.

Second, by and large, studies conducted to date have suffered from extremely poor experimental design, lack of controls, and lack of replication, and when present, pseudoreplication; mismatches between the scale of the problem and the scale of investigation, and a general tendency to be reactive, post-hoc designed studies developed as part of a mitigation strategy to allow continued development instead of an a-priori designed adaptive management process. These difficult problems provide managers little guidance on how to minimize the negative effects of continuing energy development at the population level.

Fortunately, Montana Fish Wildlife and Parks, along with other key partners, including industry, have a successful history of working together to assess the impacts of human development on ungulates at large scales. The Montana Cooperative Elk Forestry study epitomizes the cutting edge of forestry-wildlife relationships at its time, with 6 replicated studies across the state of Montana (Fig. 8). The study monitored the results of different management treatments on elk response to human activity across different spatial scales. This time, the stakes of development will be higher, with the projected impacts of energy development potentially exceeding impacts of logging in the western half of the state.

Clearly, designing long-term replicated studies across several locations in eastern and central Montana (potentially even replicated across states such as in the Upper Green River Basin of Wyoming) represents the next step in developing a scientific assessment of the effects of energy development on ungulates. Basic principles of experimental design should be followed, with control and replicate treatment populations monitored across similar habitats for a sufficient duration (10-years) to determine population level responses. Gill (2001) provides useful recommendations for large scale, population-level experiments in their review of the underlying causes of mule deer declines in Colorado. Building on the meta-analysis of the effects of energy development on wildlife, power-analyses (Gerrodette 1987) could be conducted to determine the appropriate study duration to ensure that population level responses are documented a-priori. This would alleviate the problem of uncertainty over impacts where ongoing studies fail to show any population responses in initial years of the study (Berger et al. 2007,Sawyer et al. 2006) – if a-priori power analysis confirmed that it will take 10 years to determine even small changes in adult female survival of ungulates (e.g., 4%), then preliminary analyses would be interpreted within the limits of statistical power. In that case, based on the expected treatment responses and appropriate scales of investigation of the population (see migration section above), well designed, replicated experiments between developed and undeveloped areas could be implemented that would allow MTFWP to rigorously test for the effects of energy development on wildlife.

However, this approach will ultimately fail if the current policy for energy development is incompatible with wildlife conservation. Some have criticized the current policy as an incremental energy development policy where development is approved on a piecemeal and uncoordinated basis in a linearly increasing fashion (Lustig 2002, Nelleman et al. 2003). From a policy perspective, we are currently operating under the hypothesis that wildlife and continued incremental development are sustainable. If we really want to advance wildlife conservation under energy development, we should endeavor to test this hypothesis by comparing this policy against alternative policies. **To advance our understanding of how to mitigate energy-wildlife conflicts two things are required; 1) innovative new policies for large-scale energy development, and 2) an adaptive management approach.**

4.6.4 An Adaptive Management Framework for Assessing the Cumulative Impacts of Energy Development on Ungulates

Walters (1986) defined the adaptive management process as follows: "the central tenet that management involves a continual learning process that cannot conveniently be separated into functions like research' and ongoing regulatory activities,' and probably never converges to a state of blissful equilibrium involving full knowledge and optimum productivity." Adaptive management has often been co-opted by management agencies to mean “learning by doing," but Walters (1997) criticizes many management agencies for missing the critical point of adaptive management – experimentation, controls, and adequate monitoring – without these key steps, there is no difference between adaptive management and ‘regular’ management that seeks only to satisfy short-term objectives without ensuring that long-term problems are adequately addressed. Walters (1986) describes the adaptive management process of:

1. Bounding management problems and recognizing constraints;
2. Representing existing knowledge in models of dynamic behavior that identify assumptions and predictions so experience can further learning;
3. Representing uncertainty and identify alternate hypotheses;
4. Designing policies to provide continued resource productivity and opportunities for learning in experimental comparisons of policies. (Fig. 16)

Adaptive management has been applied previously to large scale environmental problems in the United States with great success. Bormann et al. (1998) proposed an adaptive management process for the Pacific Northwest in response to concerns sparked by the spotted owl controversy - the Northwest Forest plan that affected a huge geographical area. The plan proposed 10 adaptive management areas with different management policies for forest management, and developed a framework for managers, scientists, and industry to determine improvements to policies that would allow societal goals for resource extraction to be met while minimizing negative environmental effects.

An adaptive management experiment on the effects of energy development on ungulates in Montana would help address proposed changes to energy regulation that are hypothesized to minimize negative effects of development. At present, the policy for energy development could be described as “incrementalist’, where gradually, phased development increases at regional scales in incremental steps until the entire area is brought into energy development. Under this policy, the % area affected by development will increase continually over time. Impacts are only assessed at small, local scales, usually at the scale of individual wellsite developments. Small scale timing restrictions (i.e., no drilling on winter ranges, calving ranges, etc.) represent the policy hypothesis that the main impacts of development are behavioral only, and that through avoidance of key behavioral periods, development impacts can be minimized.

Moreover, management policies designed to minimize development impacts at these small scales are hypothesized to mitigate impacts at the larger, regional scale. Both the small and large-scale predictions of this management hypothesis are as yet untested. This model of development is the current favored policy alternative amongst federal and state energy regulators by default.

An alternate policy that has been proposed could be called ‘phased’ or spatially concentrated development where energy development is concentrated geographically to maximize extraction rates of resources, minimize the % area developed, and localize impacts. Under this policy, rehabilitation of the developments would be encouraged as policy before additional sites were developed, and the overall population level impacts on key wildlife species is hypothesized to be ameliorated compared to incremental development. The predicted area impacted would be expected to increase non-linearly to some asymptotic threshold determined by the rate of new phases coming on-line and cycling through the development and restoration phase.

A third policy could be described as a protected area policy that identifies core areas for multiple species (e.g., pronghorn, mule deer, sage grouse, sage brush) that are protected from oil and gas development to provide critical habitat for threatened or (potentially) endangered species, and the ecosystems on which they depend (i.e., sagebrush steppe). This would ensure viable populations at some large, landscape scale that maintained populations and connectivity while allowing incremental development outside of these protected core areas. This is a model that is gaining support for threatened boreal caribou based on the scientific evidence that present levels of industrial development in many herds exceeds critical thresholds, causing populations to decline. Predicted area impacted under this policy would be expected to asymptotically increase to some threshold similarly to the phased policy, but the threshold would be set by the % of the landscape protected under core areas.

Under adaptive management, these ‘simplified’ policy alternates could be scientifically evaluated by encouraging development under the three hypothetical policies in two ecologically similar areas, and by monitoring responses of key wildlife (ungulate) populations at these two sites, and a similar experimental control population, over the duration of the energy development project (10-20 years long-term), in a replicated design. Whether these policy alternatives are indeed, reasonable is beyond the scope of this review. The critical point is that under adaptive management, resource extraction would be permitted to continue in a controlled fashion, embedded within an adaptive management framework that would ensure that 20 years from now, additional reviews on the effects of energy development on wildlife have something to report, and not just review another batch of poorly designed studies that fail to address the pressing policy decisions facing wildlife and land managers.

Fig.16 . Conceptual diagram of adaptive resource management as defined by Walters (1986, adapted from http://www.cmar.csiro.au/research/mse). Critically, management experiments are designed that contrast results of management experiments on key ecological indicators between control and treatment areas.

5.0 MANAGEMENT IMPLICATIONS

Based on this review, I draw the following conclusions regarding the impacts of energy development on wildlife populations.

1) **The current management policy for energy development makes two untested assumptions regarding the effects of energy development on wildlife.** First, it assumes that negative impacts of energy development on wildlife can be mitigated through small-scale stipulations that regulate the timing and duration of activity, but not the amount. This current policy also assumes that wildlife populations can withstand continued, incremental development. Neither of these two assumptions are supported or refuted by evidence reviewed in the scientific literature as part of this review. Regardless, adaptive experiments to explicitly test these management hypotheses are needed.

2) **There is currently no rigorous scientific evidence that energy development will have population-level impacts on pronghorn, mule deer or elk in eastern or central Montana.** However, this is because there have been no properly designed, thoughtful, rigorous tests of the population-level impacts conducted to date. Instead, a host of observational studies on small-scale and short-term responses provides limited guidance to managers in search of the crucial question of population impacts. While theoretically justified, relying on the precautionary principle to restrict energy development will likely be unsuccessful as an energy development policy.

3) **Short-term and small-scale impacts of energy development have been relatively well described in previous reviews and studies, albeit most often in poorly designed observational studies.** GPS collar studies have aided attempts to document small-scale responses to development, and will continue to be useful in the future in this correlational framework. Ungulates predictably avoid areas during active exploration and drilling, moving to denser cover and areas farther from human activity. Recommendations from previous studies still hold, namely timing and seasonal restrictions for critical habitats and resources. Across studies, ungulates showed avoidance responses to human development an average of 1000m from the human disturbance.

4) **Scaling up from small-scale/short-term studies to population-level impacts will be difficult.** One of the key difficulties is scaling up responses of ungulates at low development densities to high densities present in heavily developed oilfields (e.g. Upper Green River Basin). Preliminary analyses suggest that thresholds for significant impacts on ungulates will occur between densities of 0.1 to 0.5 wells/km^2 and 0.2 to 1.0 linear km/km^2 of roads and linear developments. However, these results are preliminary, and more formal meta-analyses are suggested.

5) **Building on the strong example of the Montana Cooperative Elk-Logging study that ran through the 1970's and 1980's, a series of research and management recommendations are made.**

   a. First, a formal **meta-analyses** of the existing energy literature is recommended to allow scientifically defensible quantitative estimates of the effects of energy development on behavior, habitat and population dynamics.

   b. Second, building on this meta-analysis, a **power analysis** of the optimal experimental design, level of replication, and duration of a energy-impact study design should be conducted to reveal the best approach for both short-term (behavior, habitat) and long-term impact assessment.

   c. Third, a series of **large-scale, population-level and long-term experimental comparisons** similar to the Montana Cooperative Elk-Logging study should be initiated in eastern and central Montana on elk, mule deer and pronghorn. The study design should be replicated ideally across three levels of development; none – control, initial phases –low densities of wells/roads, and after at least a decade of intensive development, to allow a rigorous test of the population effects of energy development on wildlife. Partnerships with existing studies occurring in other developed areas should be developed (e.g., Upper Green River Basin studies), but control areas in Montana should be developed (e.g., Charles M. Russell Wildlife Refuge).

   d. Fourth, implement an **adaptive management experiment** (in conjunction with the third point above) to test whether the current energy policy is sustainable from a wildlife population perspective. The de-facto energy policy as being implemented in Montana (and elsewhere) makes a number of assumptions that may in fact be incorrect. However, no serious alternatives have been developed or put forward as serious contenders that could be compared in large management experiments to test whether different models for energy development are required. If the bleak situation for Alberta caribou is any suggestion, alternative energy development policies are sorely needed.

6.0 LITERATURE REVIEW

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Appendix A: Electronic Database

Ungulate Energy Development Literature Citation Database

This searchable electronic database contains literature and research summaries on all aspects of the effects of energy development on ungulates. This exhaustive database contains all journal papers, conference proceedings, M.S. and Ph.D. theses, government reports, and other unpublished manuscripts concerning ungulates (Bighorn Sheep (*Ovis canadensis*), American pronghorn (*Antilocapra antilocapra*), Elk (*Cervus elaphus*), Mule deer (*Odocoileus hemionus*), woodland caribou (*Rangifer tarandus*)). The database was made using multiple search methods and bibliographic sources.

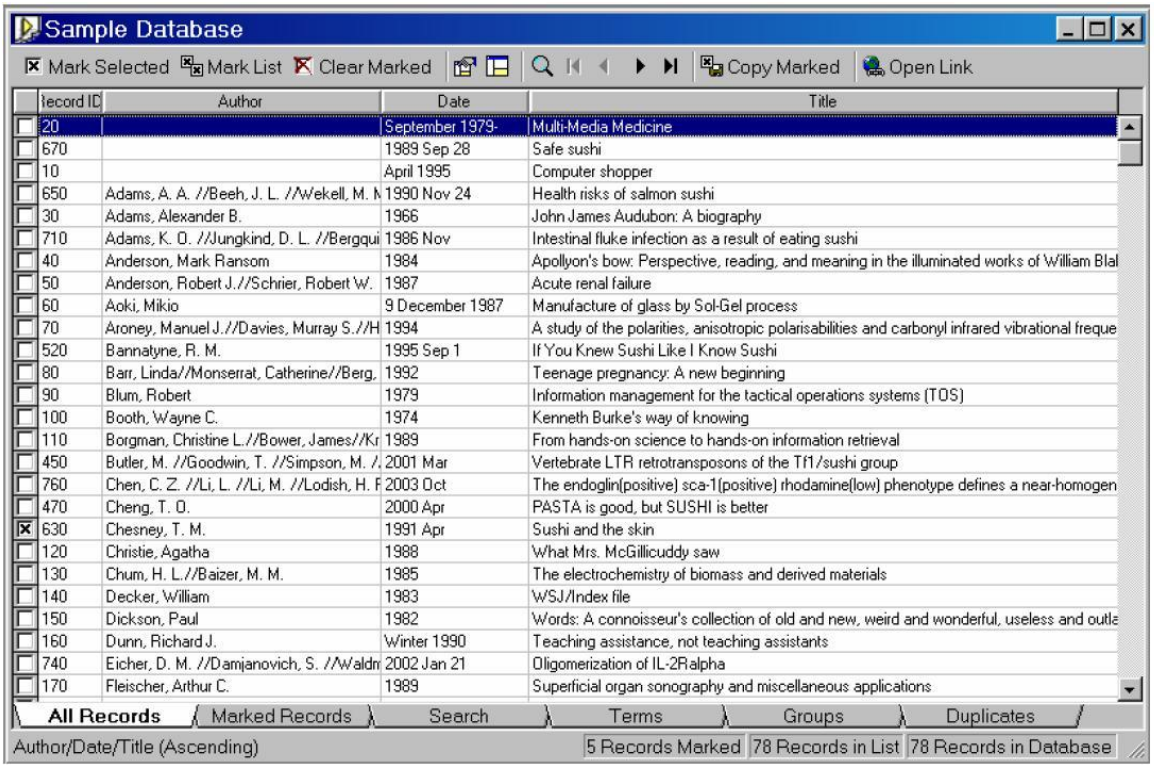
The database utilizes ProCite 5, a commercial reference management software.

To open the Wild Energy database:

1. Start ProCite

2. A file **Open** dialog displays for you to locate and open a database. If not, go to the **File** menu and choose **Open.**

The database window displays a record list of abbreviated records. By default the first Author field, Title field and Date field are shown from each record.



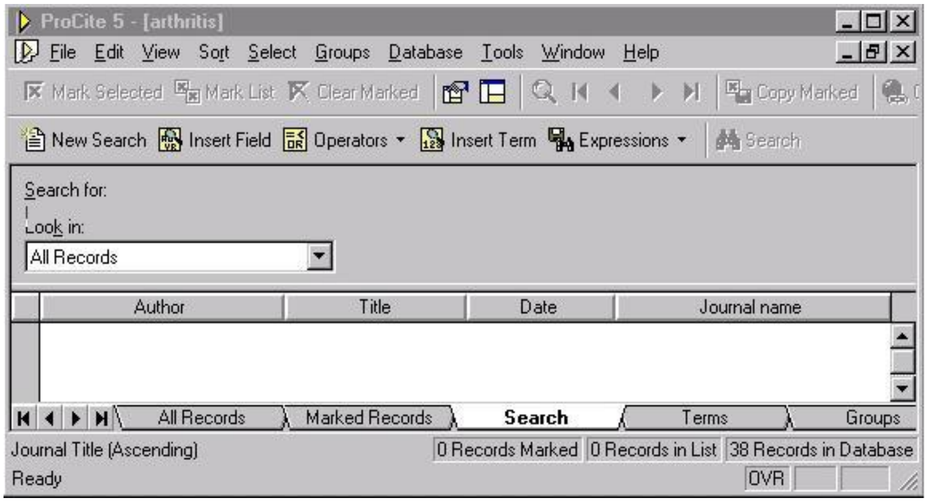
	Record ID	Author	Date	Title
☐	20		September 1979-	Multi-Media Medicine
☐	670		1989 Sep 28	Safe sushi
☐	10		April 1995	Computer shopper
☐	650	Adams, A. A. //Beeh, J. L. //Wekell, M. M	1990 Nov 24	Health risks of salmon sushi
☐	30	Adams, Alexander B.	1966	John James Audubon: A biography
☐	710	Adams, K. O. //Jungkind, D. L. //Bergqui	1986 Nov	Intestinal fluke infection as a result of eating sushi
☐	40	Anderson, Mark Ransom	1984	Apollyon's bow: Perspective, reading, and meaning in the illuminated works of William Blal
☐	50	Anderson, Robert J.//Schrier, Robert W.	1987	Acute renal failure
☐	60	Aoki, Mikio	9 December 1987	Manufacture of glass by Sol-Gel process
☐	70	Aroney, Manuel J.//Davies, Murray S.//H	1994	A study of the polarities, anisotropic polarisabilities and carbonyl infrared vibrational freque
☐	520	Bannatyne, R. M.	1995 Sep 1	If You Knew Sushi Like I Know Sushi
☐	80	Barr, Linda//Monserrat, Catherine//Berg,	1992	Teenage pregnancy: A new beginning
☐	90	Blum, Robert	1979	Information management for the tactical operations systems (TOS)
☐	100	Booth, Wayne C.	1974	Kenneth Burke's way of knowing
☐	110	Borgman, Christine L.//Bower, James//Kr	1989	From hands-on science to hands-on information retrieval
☐	450	Butler, M. //Goodwin, T. //Simpson, M. /.	2001 Mar	Vertebrate LTR retrotransposons of the Tf1/sushi group
☐	760	Chen, C. Z. //Li, L. //Li, M. //Lodish, H. F	2003 Oct	The endoglin(positive) sca-1(positive) rhodamine(low) phenotype defines a near-homogen
☐	470	Cheng, T. O.	2000 Apr	PASTA is good, but SUSHI is better
☒	630	Chesney, T. M.	1991 Apr	Sushi and the skin
☐	120	Christie, Agatha	1988	What Mrs. McGillicuddy saw
☐	130	Chum, H. L.//Baizer, M. M.	1985	The electrochemistry of biomass and derived materials
☐	140	Decker, William	1983	WSJ/Index file
☐	150	Dickson, Paul	1982	Words: A connoisseur's collection of old and new, weird and wonderful, useless and outla
☐	160	Dunn, Richard J.	Winter 1990	Teaching assistance, not teaching assistants
☐	740	Eicher, D. M. //Damjanovich, S. //Waldm	2002 Jan 21	Oligomerization of IL-2Ralpha
☐	170	Fleischer, Arthur C.	1989	Superficial organ sonography and miscellaneous applications

A status line at the bottom of the window indicates the sort order (Author/Title/Date in ascending order by default), the number of records marked, the number of records displayed in the current list and the total number of records in the database.

Double click on a specific reference to view the detailed data record.

Searching the database:

1. Click on the **Search** tab at the bottom of the window.



You can enter search terms, use Boolean operators, and limit your search to certain fields. All records that fit your search will be presented as a group in the results box at the bottom of the screen.

To launch a PDF found in ProCite's Location/URL field:

1. Double-click a record to display the full record.

2. Locate the *Location/URL (38)* field.

3. If there is a file path location in the field, the PDF is linked to the record.

4. From the **Tools** menu, choose **Open File/URL** or click the toolbar icon. ProCite launches the application that opens the PDF.

Note: You are not required to display the full record. You can launch a URL from a record list by highlighting the record and using the Open File/URL toolbar icon.

Assistance with ProCite:

1. ProCite Web Site - http://www.procite.com

The ProCite web site has a great deal of useful information on using ProCite, including a frequently asked questions page, a user email discussion list, and a free demo version of ProCite.

2. Using ProCite 5: A Guided Tour - http://www.procite.com/support/docs/ProCite%205%20Guided%20Tour-2005.pdf

This tour contains detailed information on how to manipulate and utilize the ProCite database.

Appendix B: Management Guidelines

Management guidelines developed to minimize the impacts of oil and gas development in north-central Montana (Interagency Technical Committee 1987) cited in Irby et al. (1988).

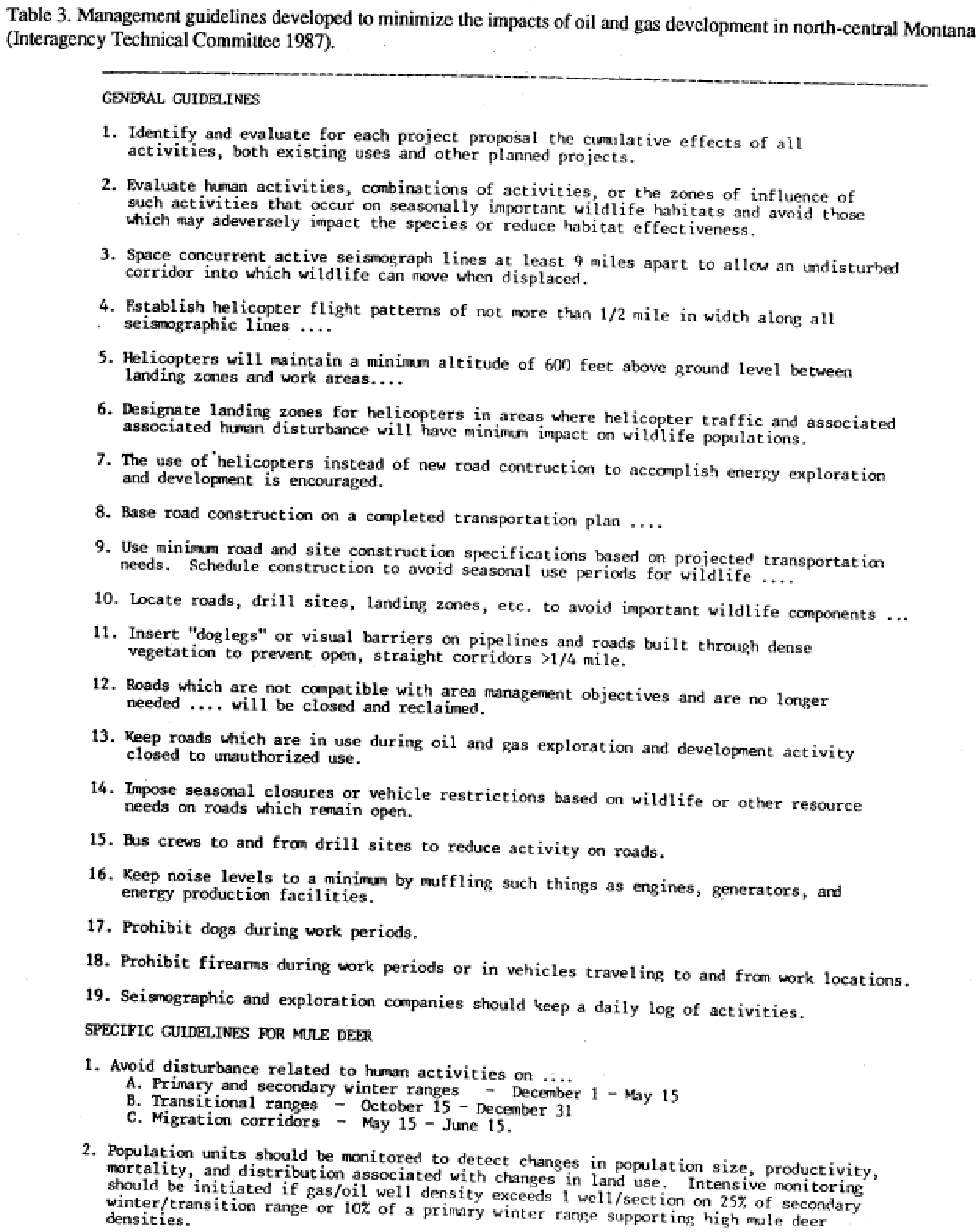


Table 3. Management guidelines developed to minimize the impacts of oil and gas development in north-central Montana (Interagency Technical Committee 1987).

GENERAL GUIDELINES

1. Identify and evaluate for each project proposal the cumulative effects of all activities, both existing uses and other planned projects.
2. Evaluate human activities, combinations of activities, or the zones of influence of such activities that occur on seasonally important wildlife habitats and avoid those which may adeversely impact the species or reduce habitat effectiveness.
3. Space concurrent active seismograph lines at least 9 miles apart to allow an undisturbed corridor into which wildlife can move when displaced.
4. Establish helicopter flight patterns of not more than 1/2 mile in width along all seismographic lines ....
5. Helicopters will maintain a minimum altitude of 600 feet above ground level between landing zones and work areas....
6. Designate landing zones for helicopters in areas where helicopter traffic and associated associated human disturbance will have minimum impact on wildlife populations.
7. The use of helicopters instead of new road contruction to accomplish energy exploration and development is encouraged.
8. Base road construction on a completed transportation plan ....
9. Use minimum road and site construction specifications based on projected transportation needs. Schedule construction to avoid seasonal use periods for wildlife ....
10. Locate roads, drill sites, landing zones, etc. to avoid important wildlife components ...
11. Insert "doglegs" or visual barriers on pipelines and roads built through dense vegetation to prevent open, straight corridors >1/4 mile.
12. Roads which are not compatible with area management objectives and are no longer needed .... will be closed and reclaimed.
13. Keep roads which are in use during oil and gas exploration and development activity closed to unauthorized use.
14. Impose seasonal closures or vehicle restrictions based on wildlife or other resource needs on roads which remain open.
15. Bus crews to and from drill sites to reduce activity on roads.
16. Keep noise levels to a minimum by muffling such things as engines, generators, and energy production facilities.
17. Prohibit dogs during work periods.
18. Prohibit firearms during work periods or in vehicles traveling to and from work locations.
19. Seismographic and exploration companies should keep a daily log of activities.

SPECIFIC GUIDELINES FOR MULE DEER

1. Avoid disturbance related to human activities on ....
   A. Primary and secondary winter ranges - December 1 - May 15
   B. Transitional ranges - October 15 - December 31
   C. Migration corridors - May 15 - June 15.
2. Population units should be monitored to detect changes in population size, productivity, mortality, and distribution associated with changes in land use. Intensive monitoring should be initiated if gas/oil well density exceeds 1 well/section on 25% of secondary winter/transition range or 10% of a primary winter range supporting high mule deer densities.