American Journal of Agricultural Economics Advance Access published January 10, 2014

CRYING WOLF? A SPATIAL ANALYSIS OF WOLF LOCATION AND DEPREDATIONS ON CALF WEIGHT

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Combining a novel panel dataset of 18 Montana ranches with spatial data on known wolf pack locations and satellite-generated climatological data from 1995-2010, we estimate the spatial impact of changing wolf pack locations and confirmed wolf depredations on the weight of beef calves. We find no evidence that wolf packs with home ranges that overlap ranches have any detrimental effects on calf weights. Other non-wolf factors, notably climate and individual ranch-specific husbandry practices, explained the majority of the variation in the weight of calves. However, ranches that experienced a confirmed cattle depredation by wolves had a negative and statistically significant impact of approximately 22 pounds on the average calf weight across their herd, possibly due to inefficient foraging behavior or stress to mother cows. For ranches experiencing confirmed depredation, the costs of these indirect weight losses are shown to potentially be greater than the costs of direct depredation losses that have, in the past, been the only form of compensation for ranchers who have suffered wolf depredations. These results demonstrate a potentially important and understudied aspect of economic conflict arising from the protection and funding of endangered species recovery programs.

Key words: calf weight, endangered species, livestock depredation, natural resources, wildlife management, wolves.

JEL codes: Q12, Q51, Q57.

The 1995 reintroduction of the gray wolf to Yellowstone National Park and northern Idaho rekindled a decades-long debate on the social benefits and costs of wolves on the natural landscape (Hebblewhite and Smith 2011). Proponents argue (Robbins 2006) that wolves are being returned to their natural habitat and provide important ecological functions as a predator at the top of the food chain, while opponents have (Steele et al. 2013) countered that wolves prey on game animals (such as elk, moose, and deer) and livestock that are crucial to the livelihoods and way of life of many in the West. The 2009 delisting of the gray wolf from the Endangered Species Act (ESA) and subsequent court cases has only intensified an often emotionally-charged public discourse. The total costs and benefits of wolves on the natural landscape are varied and intricate, and typically accrue differentially to urban and rural economies. In this paper, we focus on one intriguing and understudied component of the costs of recovering wolf populations: the indirect effects of wolf location and wolf depredations on the weight of domestic calves.

The effects of wolves on calf weights is an important empirical and policy-related issue in and of itself, as recovering wolf populations have increasingly led to conflicts between wolves and livestock (Muhly and Musianai 2009) in the western United States, and there has been concern that

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Amer. J. Agr. Econ. 1–26; doi: 10.1093/ajae/aat100

costs to ranches, other than direct depredation, have not been adequately estimated or accounted for. However, the issue of indirect costs of wolves on calf weight is more broadly important for better understanding potential economic conflicts and funding mechanisms of endangered species recovery programs under the ESA. Several studies have estimated the effectiveness of the ESA in protecting endangered species, as well as the factors that influence the inclusion of a species for protection or funding (Metrick and Weitzman 1996; Dawson and Shogren 2001; Kerkvliet and Langpap 2007; Ferraro, McIntosh, and Ospina; 2007; Langpap and Kerkvliet 2010). Two salient issues from this literature that relate to this study are: (*a*) species that are more likely to disrupt economic development are more likely to receive funding (Metrick and Weitzman 1996) for recovery[1]; and (*b*) the ESA by itself has had little impact on the recovery of species unless designation is also accompanied with funding (Ferraro, McIntosh, and Ospina 2007). To the extent that funding, as well as appropriate funding mechanisms, are necessary to mitigate economic conflict for the successful recovery of endangered species, a more complete understanding of the specific nature of the costs of economic conflicts are necessary for successfully implementing recovery programs. This study addresses a specific and previously undocumented source of conflict between the economic development of cattle ranchers and the recovery efforts of the northern gray wolf.

Historically, studies examining the impact of predators such as wolves on domestic livestock have been conducted using direct depredation rates (Sommers et al. 2010; Muhly and Musiani 2009; Bradley and Pletscher 2005; Bradley et al. 2005; Breck and Meier 2004; Oakleaf, Mack, and Murray 2003; Treves et al. 2002; Stahl et al. 2001). However, it has been suggested that predators may have impacts on livestock that reach beyond direct depredation (Kluever et al. 2008; Howery and DeLiberto 2004). One claim in particular is that wolves decrease the average weight of calves (Alderman 2006; Steele et al. 2013) by stressing mother cattle, increasing movement rates, or encouraging inefficient foraging behavior. To date, no studies have empirically estimated the indirect effects that wolves have on calf weight. Is it the case that ranchers are simply "crying wolf," or is there evidence that wolves have indirect effects on calf weight? To answer the question, we combine a novel panel dataset on 18 ranches in Montana with satellite-generated climatological and forage data with spatial data on known wolf packs to empirically estimate the reduced form impact of wolf location and confirmed wolf depredations on calf weight. We do not find statistically significant effects of wolf home range locations on calf weight for our sample ranches. However, we do find that when there is at least one confirmed cattle depredation by wolves on a ranch, there is a negative and statistically significant effect on calf weights. All else being equal, calves that are pastured on a ranch where a confirmed wolf depredation occurs are 3.5%, or 22 pounds, lighter than calves pastured on the same ranch without a confirmed wolf depredation. For the average ranch in our sample, this weight loss translates into a $6,679 loss in revenue when calves are sold. Thus, while wolf home ranges that overlap calf pastures do not have any significant effects on calf weights, ranchers are not simply "crying wolf" on ranches where wolves kill cattle.

While the focus of our study is on the effects of wolves on cattle in Montana, livestock producers across North America, as well as globally, face similar challenges addressing livestock depredation by wolves and other large carnivores (Treves and Karanth 2003; Woodroffe et al. 2005; Baker et al. 2008). Indeed, human-wildlife conflict over agricultural crop or livestock damage is one of the most important factors facing some developing nation's economies, human health, and welfare (Woodroffe et al. 2005). Moreover, as increased public tolerance and protective legislation such as the ESA contribute to recovering carnivore populations across much of the western hemisphere, livestock producers increasingly bear the economic burdens of livestock depredation.

In general, the problem of livestock or crop loss due to predators has typically been

[1] While this result is potentially important for funding decisions under the ESA, the result is not conclusive in the literature. Using a fixed effects estimator on a 4-year panel dataset, Dawson and Shogren (2001) do find a positive effect of conflict with economic development on funding, but the coefficient is not statistically significant. Their result indicates that a general notion of conflict with economic development may be correlated with unobserved species-level characteristics, highlighting the need for studies such as this to better identify the specific sources of economic conflict associated with particular species.

addressed using incentive-based (a priori) or reactive compensation schemes (Muhly and Musiani 2009; Treves and Karanth 2003; Baker et al. 2008). For example, in Norway, domestic reindeer producers are compensated for each wolverine family on their grazing area according to estimates of wolverine depredation (Hobbs et al. 2012). In North America, it has often been non-governmental compensation schemes that reimburse producers after documentation of a confirmed livestock loss to predators. The Defenders of Wildlife livestock compensation program, which existed prior to the delisting of the gray wolf in the Northern Rocky Mountains, is a prime example (Muhly and Musiani 2009). Other market-based approaches that reward livestock producers who adopt carnivore "friendly" practices and then transfer the additional costs to consumers who are willing to pay premiums for these services have also been explored (Naughton-Treves et al. 2003). Regardless of which strategy is adopted to reduce carnivore-conflict and the financial burden of depredations on producers, all approaches require both direct, and as we demonstrate here, indirect estimates of costs on livestock producers. The results of this study regarding the importance of indirect costs of wolf depredation could be developed and applied to compensation or market-based schemes in thinking about future wolf-related policies, but also are informative in thinking about potential sources of economic conflict related to other predatory species.

In the next section, we present some background on wolves, Montana cattle ranching, and the compensation programs that have been in place over the past decade for ranchers who are directly affected by wolf predation. We then present the empirical model and the data used in the analysis, as well as the relationship between the model and the relevant literature. In the final sections, we present the results of our analysis, as well as a discussion of the economic impacts of the results and conclusions.

Background

During the 1804–1806 Lewis and Clark Expedition, gray wolves roamed freely and extensively throughout the mountains and grasslands of what is present-day Montana (Young and Goldman 1944). However, it was not long before cattleman began driving herds of cattle up from Texas in search of pastureland for their stock (Power and Barrett 2001), and much of wolves' natural prey—such as bison, elk, and deer—were hunted to near-extinction by western settlers. The loss of natural prey led to wolves and other predatory species posing an increasing depredation threat to the growing livestock industry, and predators were subsequently targeted for eradication. Wolf bounty laws were enacted in 1884 to accelerate the process of wolf eradication, and by 1936 self-sustaining wolf populations were said to be extinct in Montana (Riley, Nesslage, and Maurer 2004; Mech 1970).

This remained true until the late 1970s, when wolves from Canada began to move south and naturally recolonize Glacier National Park (GNP) in northern Montana. During the 1980s, wolves slowly began to den and reproduce in GNP, which represented the first signs of a resident wolf population in Montana since the 1930s (Ream, Fairchild, Boyd, and Blakesley 1989). Since then, the resident wolf population in northwestern Montana has increased naturally (Boyd et al. 1995; Ream, Fairchild, Boyd, and Blakesley 1989).

In an effort to fully restore the gray wolf under the ESA, the U.S. Congress directed the U.S. Fish and Wildlife Service (USFWS) to facilitate recovery by actively reintroducing the gray wolf into other suitable areas of the U.S. Northern Rockies, such as Yellowstone National Park (YNP) and central Idaho (USFWS 1987). After reintroduction, wolf numbers and distribution steadily expanded beyond YNP, encompassing both public and private lands. As a consequence, rural ranchers saw an increase in wolf inhabitance on and around their lands. As of 2010, the Montana wolf population had grown to an estimated minimum number of 566 wolves (Sime et al. 2011).

The increased interaction between wolves and livestock in Montana has led to documented effects on the state's ranching industry. In 2010, the U.S. Department of Agriculture's Wildlife Service (WS) confirmed that 87 cattle were killed by wolves statewide. However, the interaction between wolves and livestock goes beyond these simple statistics, as many of Montana's wolves routinely encounter, but do not kill, domestic livestock (Sime et al. 2007).

Compensation to Ranchers for Wolf Depredation of Livestock

Direct injury or death of cattle due to wolves is the most evident negative effect that wolves have on cattle ranchers. Although domestic cattle are not natural prey for wolves, they have become a food target of wolf packs in the United States due to their abundance and vulnerability (Harper, Paul, and Mech 2005). These depredations have resulted in monetary losses to individual ranchers that have been addressed, at least partially, through economic compensation for lost livestock.

For Montana ranchers to receive monetary compensation for losses due to wolves, the killed or injured animal must be investigated by a WS agent, who will issue a report on their expert opinions on the incident. One of three possible conclusions will be submitted: it is “confirmed”[2] that predators were the cause of the death or injury; it is “probable”[3] that the incident was predator-related; or there is inconclusive evidence to attribute the incident to predator activity. The investigating WS agent also determines the species of predator (i.e., wolf, bear, coyote, mountain lion, etc.) if it was an instance of predation. For ranchers to receive monetary compensation for their loss, the investigating agent must conclude that their loss was either a “confirmed” or “probable” wolf depredation incident.

The first available compensation for Montana ranchers affected by wolf depredations was offered in 1987 from the Defenders of Wildlife (DOW), a non-governmental environmental organization, who designated $100,000 to compensate American ranchers in the northern Rocky Mountains for livestock lost to confirmed wolf predation. In 1997, the compensation fund was officially named the Defenders of Wildlife Wolf Compensation Trust, and the fund was doubled to $200,000 in 1999 (Background on Defenders of Wildlife Wolf Compensation Trust 2011). The DOW paid full value for a confirmed wolf depredation incident, and 50% of the determined value of the livestock for a probable wolf predation incident. Though the assessed value of the animal in question may have been higher, the DOW capped compensation at $3,000 per lost animal (Frequently Asked Questions about the Wolf Compensation Trust 2011).

From 1987 through 2009, the DOW issued $429,880 in compensation for wolf depredations of livestock in Montana; included in this statistic is $100,000 given to Montana to help initiate a state-run compensation fund for ranchers who experienced wolf predation.[4] With Montana’s program underway following the delisting of wolves in 2009, the DOW ceased directly compensating ranchers in September 2010.

In 2007, the Montana legislature created the Montana Livestock Loss Reduction and Mitigation Board (LLRMB), which currently acts as the sole means of reimbursement to Montana livestock producers for “confirmed” and “probable” livestock losses due to wolf depredation. In 2011, the LLRMB issued just over $75,000 in compensation to ranchers for cattle losses due to wolf predation in Montana.[5]

Montana Cattle Ranching

Cattle ranches in Montana are predominately cow-calf operations. Mature female cows are bred to bulls in the summer, and give birth to calves in late winter or early spring of the following year.[6] While calves are still nursing, the cow-calf pairs are let out to pasture for the summer and early fall to graze. Montana

[2] Confirmed is defined by USDA Wildlife Services to be: “Reasonable physical evidence that livestock was actually attacked or killed by a wolf, including but not limited to the presence of bite marks indicative of the spacing of canine tooth punctures of wolves and associated subcutaneous hemorrhaging and tissue damage indicating that the attack occurred while the animal was alive, feeding patterns on the carcass, fresh tracks, scat, hair rubbed off on fences or brush, eyewitness accounts, or other physical evidence that allows a reasonable inference of wolf predation on an animal that has been largely consumed” (Montana State Legislature 2009).

[3] Probable is defined by USDA Wildlife Services to be: “The presence of some evidence to suggest possible predation but a lack of sufficient evidence to clearly confirm predation by a particular species. A kill may be classified as probable depending on factors including but not limited to recent confirmed predation by the suspected depredating species in the same or nearby area, recent observation of the livestock by the owner or the owner’s employees, and telemetry monitoring data, sightings, howling, or fresh tracks suggesting that the suspected depredating species may have been in the area when the depredation occurred” (Montana State Legislature 2009).

[4] Wolf Compensation Payment Statistics, n.d. Wolf Compensation Payment Statistics. (n.d.). http://www.defenders.org/resources/publications/programs_and_policy/wild life_conservation/solutions/statistics_on_payments_from_the_defenders_wildlife_foundation_wolf_compensation_trust.pdf.

[5] http://liv.mt.gov/LLB/lossdata.mcpx.

[6] Agriculture and Business. 2007. Retrieved February 16, 2011, from http://montanakids.com/agriculture_and_business/farm_animals/Cattle.htm.

summer pasture for cattle is privately deeded or public land is leased to a ranch by the U.S. Bureau of Land Management (BLM) or the U.S. Forest Service, which is referred to as a grazing allotment.

Calves stay with the mother cows for about 6 months until they are weaned in the fall, and then generally sold as feeder calves.[7,8] Livestock producers typically have a target in mind for what their calves should weigh at the time of weaning, and producers budget their time, finances, and other resources accordingly throughout the year based on those expectations. If, at the end of the grazing season, a herd of calves weighs less than expected, a rancher's profit margin is directly affected. Therefore, it is important to the economic sustainability of the operation that calves maintain an optimal and expected trend in weight gain over the course of the grazing season.

To identify any potential indirect effects wolves may have on calf weight in western Montana, it is imperative to understand what else may affect pre-weaning calf weight trends. In the model and discussion below, we present a review of the literature about animal husbandry and environmental factors influencing calf weight, predator/prey interactions, and the potential links between them.

Empirical Model and Data

Our empirical strategy employed a novel panel dataset containing calf-weaning weights for 18 western Montana ranches from 1995 to 2010, and combined it with ranch-specific husbandry practices, environmental and climatological spatial data, and spatial data on known wolf pack home ranges and confirmed wolf killings of livestock. Prior research on the determinants of calf weight has used linear regression techniques to estimate the effects of calf sex (Barlow, Dettmann, and Williams 1978), genetic and environmental factors (Brown, Brown, and Butts 1972), and other covariates (Cundiff, Willham, and Pratt 1966; Dal Zotto et al. 2009) on calf weight. However, the real strength of our panel dataset is that it contained ranches that have been impacted by wolf presence in some years and not in others, which allowed us to estimate the average treatment effect of known wolf activity on calf weight using a quasi-experimental panel data differences-in-differences approach. This quasi-experimental empirical approach, which allowed us to control for time-invariant unobservable characteristics across ranches, has been demonstrated to be a successful strategy for eliminating endogeneity and selection bias (Greenstone and Gayer 2009) and has been employed in other recent work on evaluating the cost-effectiveness of species recovery (Busch and Cullen 2009).

The empirical model used in this analysis builds on prior research by regressing average calf weaning weight on ranch i in year t on all measurable ranch-specific, environmental, and climatological covariates believed to have an influence on calf weight, but also includes two treatment effects for the time-variant spatial location of known wolf-pack home ranges and confirmed kills of cattle by wolves. For each ranch i in year t, there are two observations: an average heifer (female calf) weight and an average steer (male calf) weight. Calf weight is a function of ranch-specific (α_i) and year-specific (γ_t) fixed effects, a vector of time-variant climatological and environmental factors ($\mathbf{x}_{it}\boldsymbol{\beta}$), a vector of wolf treatment effects ($\mathbf{w}_{it}\boldsymbol{\eta}$), and a time-variant error term (e_{it}). The regression model is displayed in equation (1) below:

$$(1)\qquad calf\_weight_{it} = \sum_{i=1}^{18}\alpha_i + \sum_{t=1}^{16}\gamma_t + \mathbf{x}_{it}\boldsymbol{\beta} + \mathbf{w}_{it}\boldsymbol{\eta} + e_{it}.$$

Cow-calf producers have heterogeneous geographic locations and idiosyncratic styles of husbandry practices that do not change over time, but can lead to important differences in calf weight (MacGregor and Casey 2000; Brown, Brown, and Butts 1972). Ranch fixed effects are included to capture all unobserved ranch-specific characteristics (such as unobserved husbandry practices, ranch-specific data collection processes, or ranch terrain characteristics and geography such as slope and elevation) that do not change over time, while year fixed effects control for unobservable year-specific effects that are common across ranches (such as state or

[7] A feeder calf is a weaned calf sold to a feedlot where it will be fattened up for beef production.
[8] Hanawalt, K. 2011. Cutting Pairs. http://www.montanacowboycollege.com/cutting_pairs.htm.

federal policies, changes in industry norms, feed quality, or the quality of vaccination products). The vector, $\mathbf{x}_{it}$, includes ranch-level husbandry practices and environmental characteristics that change by ranch and year, $\boldsymbol{w}_{it}$ is the vector of treatment measures of wolf presence on ranch i in year t, and e_{it} is a normally distributed random error term.

One of the primary challenges of the study was to identify a random selection of ranchers in western Montana that would be willing to share their proprietary ranching and production data for their cow-calf operations. No single database of Montana cow-calf producers exists, and cow-calf producers tend to be a small proportion of the overall general population. In an effort to focus our sampling effort and identify cow-calf producers, we targeted our sample search to populations of individuals that would be most likely to contain cow-calf producers. We did this by contacting several livestock industry associations and organizations that maintain membership databases. With the help of these organizations, we randomly sampled from their membership lists. It is important to point out that membership in these organizations does not imply that the member is a cattle producer, as many of the organizations we worked with provide a variety of services and information related to agriculture and ranching, and anyone working in these industries or who has a general interest in these issues is able to join. However, obtaining a sample from these organizations' membership lists provided a more focused population to identify cow-calf producers than sampling from the general population at large. Working with these organizations,[9] 826 emails and letters were sent to a random selection of members of these organizations seeking participation, along with a brief explanation of the study and the minimum parameters for participation.[10] Ranchers willing to participate in the study were able to enter their contact information into a website (if contacted by email), or could fill out and mail in a pre-addressed, postage-paid postcard (if contacted my mail). Once a rancher submitted their contact information, they were contacted with a follow-up phone call to confirm their willingness to participate and that they were able provide the necessary survey information. If these criteria were met, an on-ranch interview was scheduled.

During the on-ranch interview, we collected ranch-specific data such as ranch-level yearly average weaning weights for both steers and heifers, and ranch-specific husbandry practices. In particular, the survey was designed to document any ranch-specific husbandry practices—such as calf breed, calving dates, hormone programs, etc.—that may have changed over time and could directly influence the weaning weight of the calves.[11] Of the 826 letters and emails sent out, 54 (6.54%) provided a return response. Of those 54 initial responses, 33 individuals were ineligible for study and were not selected for an on-ranch interview. The reasons for ineligibility varied, but were predominantly due to the fact that they were not ranchers (but responded to let us know anyway), they did not raise feeder calves, or they had not been ranching for a long enough period of time. Of those 54 individuals who responded, 21 were selected for an on-ranch interview, 18 of which were ultimately used in this study.[12] One caveat regarding the sample used in this study is the degree to which it represents the true population of cow-calf producers. Without population-level statistics on cow-calf producers in western Montana, we could not say how precisely our sample matched the true population of cow-calf producers. However, the panel nature of our data allowed us to consistently estimate within-ranch wolf, climatological, and husbandry effects for the ranches included in the sample. Thus, while we feel confident that the estimates obtained are consistent estimates for our sample ranches, extrapolations to general populations of ranches should be made with a degree of caution if the characteristics of those ranches are sufficiently different than those of the sample ranches in this study.

[9] The organizations were the Montana Cattleman's Association, the Montana Stockgrowers Association, Crazy Mountain Stockgrowers Association, Gallatin Beef Producers, Park County Stockgrowers Association, Madison-Jefferson County MSU Extension Office, Beaverhead County MSU Extension Office, and the Powell County MSU Extension Office.

[10] Minimum parameters for participation were that the ranch had to be able to provide average calf weaning weights from approximately 1995 to 2010, and that they have a minimum of 80 cow-calf pairs per year.

[11] The data from the on-ranch survey was conducted and filled out by the surveyor, not the rancher.

[12] Two of the 21 ranches that were selected for on-ranch interviews did not separate their steer and heifer calf weaning weights, and therefore were not comparable to the other 18 ranches in the study that did separate weights for steers and heifers. Therefore, these 2 ranches were not included in the analysis. A third ranch ultimately had incomplete records and several missing years of data, and was also not included in the analysis.

In the sections that follow, we discuss the data collected in the on-ranch survey, the climatological data, wolf data, and the importance of each of the covariates collected in the study for explaining calf weight.

Time-invariant Ranch-specific Husbandry Practices

In this section, we first discuss several factors that are ranch-specific and important for calf weight, but do not change over time and are assumed to be captured by the ranch-specific fixed effects in the empirical model.

Geography

Information was gathered during on-ranch interviews about where sample calves were pastured during the summer, and whether that changed over the study period. None of the 18 ranches in the sample changed pasture size or spatial location over the study's time period. Combining information about the location of ranch herds during the summer with data from the Montana Cadastral Database,[13] spatial representations of calf summer pastures for each ranch were created. Summer pasture for the ranches in the sample consists of a combination of deeded, privately, and publicly-leased land.

Age of Mother Cow

The average age of the herd has been shown to affect the weight gained by pre-weaned calves (Zalesky, LaShell, and Selzer 2007; Barlow et al. 1978; Swiger et al. 1962), while prior lactation status[14] of mother cows has been shown to influence the average daily weight gain and weaning weight of calves (Beffa, van Wyk, and Erasmus 2009). Younger mother cows demand extra forage consumption for their own physical growth, which decreases the milk production necessary for optimal calf growth (Hetzel et al. 1989; Tawonezvi 1989; Tawonezvi, Brownlee, and Ward 1986; Thorpe, Cruickshank, and Thompson 1980).

The effect of age of the mother cow on weaning weight of calves has varied across studies due to differences in breeds, genetic selection, and experimental practices. Weaning weights of calves increased with the increasing age of the mother cow, peaking for 8–10 year old dams (Beffa, van Wyk, and Erasmus 2009) in one study and 6–9 year old dams in another (Minyard and Dinkel 1965). Other researchers found the maximum production age of a cow to be between 6–10 years (Sawyer, Bogart, and Oloufa 1948; Rollins and Guilbert 1954; Burgess, Landblom, and Stonaker 1954; Nelms and Bogart 1956; McCormick, Southwell, and Warwick 1956). Barlow et al. (1978) found that weaning weights of both steer and heifer Angus calves increased as the dam aged to 4 years, while weaning weights for both sexes remained fairly constant across the cow ages of 5–8 years, inferring that the cow had reached full maturity.

The yearly replacement of older cows with younger cows with little or no previous mothering experience may impact the average calf weaning weight of a herd. Though we were not able to quantifiably account for the age of mother cows in the sample ranch herds (most ranchers surveyed did not have these detailed records), personal interviews with the ranchers indicated that the yearly replacement rate of old cows with new, younger cows within a sample ranch herd remained fairly constant from year to year. To the extent the average age of the mother cows on a ranch stayed constant over time, the effect of the mother cow's age on calf weaning weights was captured in our model by the ranch fixed effects.

Supplemental Feeding

Supplemental feeding practices positively influence weight gain and birth weights of beef calves by increasing the fat intake of prenatal cows (Dietz et al. 2003; Havstad, McInerney, and Church 1989). Pregnant cows fed rations of predominately high energy corn or dried distillers grains birth heavier calves compared to cows gaining nourishment from grass hay (Radunz et al. 2010). For cattle that demand high levels of energy to maintain productivity, such as pregnant cows and growing calves, a high-protein supplement can boost digestion efficiency,

[13] Data was downloaded from ftp://ftp.gis.mt.gov/cadastral framework. The Cadastral Database is being continually updated to account for changing land ownership status. The data used in this study were current as of 10 October 2010. See figure 8 in the appendix for a breakdown of when the county-specific data used in this study were last updated.

[14] This refers to whether or not a cow has reared a calf in the past, and is a measure of the physical experience of the mother cow.

which contributes to increased milk production and weight gain (Rinehart 2006). Other researchers concluded through a controlled experiment that feeding protein-rich food supplements to pregnant cows has no significant effect on calf weaning weight (Alderton et al. 2000).

Though feeding and grazing practices may vary across sample ranches, none of the sample ranchers indicated a change in their supplemental feeding regimens over the examined time period. Thus, the variation in supplemental feeding practices across ranches and their potential effect on calf weight is assumed to be captured by the ranch fixed effects.

Time-variant Ranch Husbandry Practices

In this section, we discuss several ranch-specific factors that are important for calf weight but potentially change across ranches and over time. These factors are not captured by the ranch-specific fixed effects in the empirical model.

Sex of Calf

The sex of the calf has consistently been shown to have an effect on calf weight gain. Barlow et al. (1978) found that male Angus calves wean 16.58 kg heavier than their female counterparts, while castrated male calves (steers)[15] have been shown to wean as much as 7% heavier than heifer calves (Beffa, van Wyk, and Erasmus 2009). Other researchers have found that steers gain approximately 5% more weight than their female counterparts of the same age and breed (Hanawalt 2011). The dependent variable in the estimation model, calf weight, was categorized by the sex of the calves represented. There are a total of 226 castrated male calf (*steer*), and 211 female calf (*heifer*) sample observations on calf weight.[16]

Calf Age

The age of a calf has been shown to be a significant factor in determining calf weight at weaning (Beffa, van Wyk, and Erasmus 2009). The effect of calf age (in days) on weaning weight has been shown to equal as much as 1.46 pounds per day controlling for sex of the calf, age of the mother cow, and year (Botkin and Whatley 1953). Others have reported the effects of age on weaning weight per day of 1.33 pounds (Koger and Knox 1945) and 1.20 pounds (Minyard and Dinkel 1965).

This study used a calculated average age of calves (in days) on a ranch to account for the effect of calf age on weaning weight. Calf age was measured as the number of days between the average median birth date and the weaning date of calves on ranch i in year t. The average median birth date of calves was calculated using the approximate birth date of the first and last calf born for each ranch i in year t. Calving season can often last for 100 days or more, but research has shown that the distribution of calves born during calving season on a ranch is roughly normally distributed, and centered on the middle of the calving season (Minyard and Dinkel 1965). Using the average median birth dates and weaning (or sale) dates, an average age (in days) of calves on ranch i in year t was calculated. Calves in the sample ranged in average age from 160 to 347 days.

Calf Breed

Several studies examining the effect of calf breeds on weaning weights have shown that breed is a determining factor in the growth and body weight of pre-weaned beef cattle (Wiltbank et al. 1966; Gregory et al. 1965; Brown, Brown, and Butts 1972), although Minyard and Dinkel (1965) found that differences in weaning weights between some breeds are insignificant. Biologists have shown that genetic selection using crossbreeding can influence weight gain and maturation trends of calves (Dal Zotto et al. 2009; MacNeil 2003; Laster, Glimp, and Gregory 1972). Birth weight and weaning weight have been shown to be affected by altering the genetic proportions of crossbred calves (Dadi et al. 2002; Skrypzeck et al. 2000). In addition, different breeds and crossbreeds yield varying conception and calving intervals, which influences breeding and calving times (Doren, Long, and Cartwright 1986). This study incorporated dummy variables for the breed (including cross-breeds) of calves on ranch i in year t to control for any possible effects of breed on calf weight. Ten different breeds and crossbreeds of

[15] Steers are male calves that have been castrated. A male calf that has not been castrated is referred to as a bull calf.

[16] There are slightly fewer heifer observations, as there were a few ranches that only recorded their steer weights for some years.

calves are observed in this study, with the most prevalent being Black Angus.

Hormone Implanting and Artificial Insemination

Some calf producers implant their calf herd with growth hormones to stimulate weight gain, which has been shown to increase average daily weight by 20% (Burroughs et al. 1955). Average daily weight gain of finishing steers[17] has been shown to increase by 16% (Rumsey et al. 1996) and as much as 23% (Kahl, Bitman, and Rumsey 1978) when implanted with a growth hormone (Synovex-S[18]) compared to steers with no growth hormones of similar physical character and raising conditions (Dimius et al. 1976; Embry and Gates 1976; Rumsey and Oltjen 1975). Not only do growth hormones stimulate increased weight gain, but some types do so while increasing feed conversion efficiency (FCE) or decreasing the necessary amount of forage needed to sustain optimal growth trends in steers (Animal and Veterinary: NADA 141-043 Synovex Plus - origional approval, 2009; Hunt et al. 1991). Research has shown that growth hormones can effectively increase the FCE of yearling steers by as much as 19% (Heinemann and Van Keuren 1962). To control for heterogeneous use of hormone implanting on ranches, which was decreasing over the sample period, we included a dummy variable indicating whether ranch i used hormone implanting in year t.

In addition, although the majority of our sample did not use artificial insemination (instead of insemination by a bull) and we are not aware of any studies to suggest that it affects calf weight, it does represent a time-variant husbandry practice that did vary across ranches. Therefore, we included a dummy variable in the estimation model for any year where calves were conceived using artificial insemination.

Stocking Density

Livestock husbandry practices, such as stocking density, can have both a direct and indirect impact on cow-calf ranching operations. At higher stocking densities, the ecological carrying capacity of a pasture may be surpassed due to overgrazing, which will result in less than adequate available forage for a herd (Rinehart 2006), and contribute to suboptimal calf weights. Higher densities may also render livestock more vulnerable to depredation (Hebblewhite 2011). At higher densities, foraging opportunities and decisions of mother cows may have a negative indirect effect on calf weight due to malnutrition. Overgrazing of rangelands is most commonly attributed to mismanagement of the land by the producer, but overuse of some foraging areas, by both wild and domestic ungulates, can result from avoiding similar areas that have an increased risk of predation (Kotler and Holt 1989).

The potential effect of the overall size of the herd is closely related to stocking density. Cattle group size and its effect on foraging efficiency and rate of vigilance has been a heavily debated topic with no clear conclusion (Elgar 1989). For other ungulates, researchers have found a negative correlation between group size and rate of vigilance in white-tailed deer (Lagory 1986), springbok in Botswana (Bednekoff and Ritter 1994), and impalas and wildebeests in South Africa (Hunter and Skinner 1998). However, others looking at elk and bison in Yellowstone National Park (Laundre, Hernandez, and Altendorf 2001) and various species of birds (Lima 1995) did not find any significant group-size effects in their research. To control for any stocking density or group size effects, we included the number of cattle on a ranch in a particular year. Since land area remains constant on each ranch, the number of cattle captures the net combined effect of stocking density and group size on calf weight.

Range Riders

Best management practices to reduce carnivore-livestock depredation are reasonably well established for wolves in North America. The basic premise is to reduce the spatial overlap of wolves and livestock, as well as reduce the vulnerability factors that render livestock more susceptible to predation. To reduce spatial overlap, range-rider programs, where "cowboys" patrol with livestock on summer range, are used to monitor wolf activity, move cattle away from areas

[17] Finishing steers are male castrated calves that have been weaned and are in the last few months of preparation before they are slaughtered for beef production.
[18] Synovex is an implant containing estradiol and progesterone used to boost weight gain of calves during the growing and finishing process of cattle production.

with abundant wolf sign, and to act as a deterrent to help minimize wolf depredations (Treves et al. 2003).

Another management practice includes selecting calf breeds that calve earlier in the season. This ensures that calves are larger in body size when turned out to pasture, reducing their vulnerability to depredation because of the known size-selectivity of wolves for smaller body sized cattle (e.g., Morehouse et al. 2012). Separating cattle during the calving period and keeping vulnerable calves in lighted yards or closer to human buildings also reduces the risk of mortality (Bradley and Pletscher 2005). In addition, fladry (long lines of flags) has been shown to reduce wolf depredation on specific pastures in spring and summer (Musiani et al. 2003). While these represent several known methods of reducing the risk of livestock depredation, there are few industry-wide accepted standards for best management practices that are adopted by livestock producers. In our sample, the only mitigation strategy employed by a small subset of ranches was the use of a range rider program. We included a dummy variable for any ranch that used a range rider program in a year. To the extent that breed selection of calves played a role in mitigating wolf interactions, these effects were captured in the model by including the breed fixed effects mentioned above.

Environmental Factors

Climate Variables

Environmental induced stress such as extreme heat and cold, dampness, or wind can negatively affect calf weight (Rinehart 2006), and these environmental factors have the greatest impact on calf weight during the first 12 months of a calf's life (Brown, Brown, and Butts 1972; Azzam et al. 1993; Beffa, van Wyk, and Erasmus 2009). For example, Kamal and Johnson (1971) find that Friesian[19] calves exposed to three consecutive days of high ambient heat can lose 15% of their body weight, while Kamal and Seif (1969) found a 27% decline in total body weight of adult Friesian cows when exposed to increased heat. In another study, Fernandez-Rivera et al. (1989) use a model to simulate environmental factors and find that calves decrease forage intake in an effort to stay warm, leading to suboptimal weight gain during periods of decreased temperatures. To control for the potential impacts of climatic changes on calf weight from year to year, average annual temperature and aggregate snowfall and precipitation measures are included in $\mathbf{x}_{it}$.

Raw data on monthly average temperature and aggregate rainfall and snowfall was obtained from the Western Regional Climate Center's (WRCC) website.[20] The data is the result of a partnership between the Cooperative Observer Program (COOP) and the National Weather Service (NWS) to gather daily meteorological data at over 700 different locations across Montana, which is then cataloged and made available for public use (Cooperative Observer Program Fact Sheet 2010). Using ArcGIS 9.3 (ESRI, Redlands, CA) software, each ranch was matched with the closest weather station to obtain daily meteorological data, which allowed us to calculate average annual temperature, aggregate annual rainfall, and aggregate annual snowfall for each ranch/year observation in the dataset. The average distance from the center of each ranch to the closest weather station was 14 miles, with the closest weather station being 2.8 miles, and the furthest weather station being 31.8 miles. The same weather station was used for each ranch over the sample period, so any time-invariant variability due to distance from the weather station is accounted for in the empirical model by the ranch-specific fixed effects.

Normalized Difference Vegetation Index

Weight gain of both wild (e.g., elk) and domestic (e.g., cattle) ungulates consists mostly of forage intake (I = kg/day) (Howery and DeLiberto 2004), which has been represented as a product of bite rate (BR = bites/minute), bite size (BS = grams/bite), and foraging time (FT = time foraging/day) (Stuth 1991), as well as forage quality, or digestibility of each bite (Van Soest 1982). Theory suggests that optimal foraging efficiency allows for the maximum amount of

[19] Friesian cows are a breed of cattle most commonly raised for dairy production.

[20] Data was downloaded from the Western Regional Climate Center's website working with the National Weather Service (NWS) Cooperative Observer Program (COOP). http://www.wrcc.dri.edu/coopmap/.

energy to be gained from the least amount of energy expended while feeding (MacArthur and Pianka, 1966). For example, as "patch" densities increase, goats increase their forage efficiency by spending more time eating and less time walking in search of food (de Knegt, Hengeveld, Langevelde, et al., 2007).

The amount of forage available to ungulates, as well as the length of the vegetative growing season, is also positively correlated with body weight (Mysterud, Langvatn, Yoccoz, and Stenseth 2002). In areas that experience faster rates of vegetative green-up (early May to early July), juvenile big horn sheep lambs grow at a slower rate than in areas that had a slower, more gradual vegetative green-up period (Pettorelli et al. 2007). Other research has produced similar results, finding that wild ungulates such as elk (Hebblewhite, Merrill, and McDermid 2008) and alpine reindeer (Pettorelli et al., 2005) are heavier in areas with longer, more gradual growing seasons than in areas with faster, more extreme vegetative green-up rates. To account for varying forage conditions where calves were raised, a Normalized Difference Vegetation Index (NDVI) that varies over space and time is incorporated to control for both the average quality of vegetative conditions, as well as the length of the growing season on each ranch.

The NDVI is a widely used measure describing the greenness or relative density and biomass of vegetation on the landscape (Pettorelli, Vik, Mysterud, et al. 2005; Thoma et al. 2002). Since 1989, a sensor known as the Advanced Very High Resolution Radiometer (AVHRR) carried on the National Oceanic and Atmospheric Administration's (NOAA weather satellites has been taking daily imagery of the earth's surface at a resolution of 1 square kilometer (Remote Sensing Phenology: NDVI from AVHRR 2011). Using the raw satellite data, remote sensing scientists use algorithms to calculate composite NDVI data that range in value from -1 to $+1$.[21] A larger calculated NDVI value represents "greener" vegetation on the ground. To create a consistent time interval for measurement across ranches and years, NDVI measures are calculated from 1 February to 30 November for ranch i in year t.

Total NDVI is the integration of the "NDVI Curve" from February through November in each year, which can be interpreted as the total amount of forage available to the cow-calf pairs on ranch i in year t (Pettorelli et al. 2006). To obtain a measure of the average amount of forage available to cow-calf pairs on a ranch in a particular year, total NDVI is averaged to obtain the mean NDVI. To measure the rate of "green-up," or the length of the growing season, the standard deviation of the "NDVI curve" for ranch i in year t was calculated. A larger standard deviation is interpreted as having a longer growing season (Pettorelli et al. 2006). All else being equal, we expect that more available forage, measured by mean NDVI, and a longer growing season, measured by the standard deviation in NDVI, will have positive effects on the weight of calves, as they would have better forage available to them over a longer period of time.

Wolf Presence Measures

In this section, we discuss some of the important effects of increased vigilance due to predation risk on forage efficiency and the variables that we used to control for these impacts on calf weight. It has been theorized that prey species choose to forage in habitats with suboptimal quantity and quality of nutrients due to increased risk of predation (Brown 1988; Howery and DeLiberto 2004), and various studies have substantiated this behavior in a variety of prey species (Kotler et al. 1991; Brown and Morgan 1995; Kotler et al. 1994). However, predator presence may also affect prey species behavior by increasing time allotted to habitat selection (Kotler and Holt 1989), thus indirectly affecting foraging efficiency and weight gain.

Increased threats of predation on the landscape require prey to balance predation risk with nutrient intake. Dubbed the "landscape of fear," researchers proposed that wild ungulates must make foraging location decisions based on both the physical layout of palatable nutrients and the changing predation risk across the landscape (Laundre, Hernandez, and Altendorf 2001). This process of balancing the need for food intake and alleviating predation risk was observed in the behavior of mule deer under predation risk of mountain lions (Altendorf et al. 2001).

The addition of a predator to a habitat that was previously a safe haven for prey

[21] The AVHRR data used in this study is in 6-day composites. Following the Patuxent Landscape Model (PLM) (n.d.), the NDVI data used in the analysis was re-scaled from 0 to 200. http://www.uvm.edu/giee/PLM/.

will change the potential energetic gains of that prey due to a number of potential mechanisms. Hunter and Skinner (1998) find that after the reintroduction of lions and cheetahs, impalas and wildebeest increased their level of vigilance by 200% and that even during significant periods of subdued cheetah and lion presence, both ungulates continued their heightened level of vigilance and foraged at suboptimal rates. In areas with wolves, female elk with calves increased their rates of vigilance compared to mother elk residing in areas with no wolves (Laundre, Hernandez, and Altendorf 2001). When mother elk perceive a threat from predators, they spend more time being vigilant and less time foraging, which can negatively influence production levels of both the mother and nursing calf. Other research comparing domestic cattle and elk suggests that cattle may be more susceptible to similar risk effects than wild herbivores such as elk (Laporte et al. 2010). Further, Muhly et al. (2010) showed that domestic cattle increased movement rates and altered habitat selection for much longer than wild elk following exposure to wolves. These increased movement rates in response to heightened predation risk may also increase energetic costs, thus decreasing calf weight. Finally, in much of western Montana, cattle also compete with wild ungulates such as elk, deer, and moose for vegetative forage (Torstenson, Tess, and Knight 2002; Alt, Frisina, and King 1992; Holechek 1980). The presence of predators in a given area may induce competing foraging species (i.e., cattle, elk, and deer) to choose the same areas to feed, thus diminishing available forage faster than if predators were not present (Kotler and Holt 1989).

Given the variety of ways that changes in predator presence may impact forage efficiency and stress, this study exploits several spatial measures of changing "wolf presence" to obtain a reduced form estimate of wolf presence on calf weight. The first measure of wolf presence used is constructed using wolf population and spatial distribution data collected through routine monitoring by USFWS from 1995–2004, and Montana Fish, Wildlife, and Parks (MFWP) from 2005–2010. Data for both periods were provided by MFWP.

The USFWS and MFWP wolf monitoring objectives were to document packs, determine minimum pack sizes, and to delineate wolf territories based on all available information. This knowledge was gathered using direct observational counts through radio telemetry, howling and track surveys, and public wolf reports (Sime et al. 2011) to estimate yearly wolf pack territories on the Montana landscape. Most territories are represented as Minimum Convex Polygons (MCPs) by connecting the outermost observation points (Kie, Baldwin, and Evans 1996; Mohr 1947). The MFWP creates yearly wolf home range MCPs by compiling documented wolf locations (mostly using radio-telemetry and GPS collars) gathered throughout the calendar year and connecting those pack-specific locations on a map to create MCPs of estimated pack home ranges in the state (Sime et al. 2011).

Some spatial characteristics of wolf territory MCPs do not perfectly estimate the true land use of wolves on the landscape. In some instances, MFWP personnel know that there are at least two wolves in a particular area (which is by definition the minimum number of wolves to be deemed as a "pack") but there was not a radio-collared member of the pack or pair. Thus, radio telemetry monitoring was not possible and an MCP cannot be delineated. In these instances, a landscape feature is selected that represents the best approximation of where a pack spends time during key segments of the year. This point was then buffered out by approximately a 4-7 kilometer radius (depending on the year of data) for the purposes of representing the pack on a map. These packs are spatially represented using a buffered point creating a uniform circle, and are referred to as "centroids."

The first wolf measure we created was a dummy variable defined to be 1 if one or more of the MFWP's wolf home range MCP's spatially "overlaps" any ranch land used for summer pasture on ranch i in year t, and zero otherwise. While the yearly wolf MCPs are delineated using the best available knowledge of wolf activity, the coarse scale and frequency with which the wolves were monitored implies that the actual wolf pack locations are measured with error. The actual size of true wolf pack home ranges used by wolves could be smaller or larger than the estimated ranges in our data. It is assumed that any possible data collection biases with respect to the size of the true wolf pack home ranges are normally distributed around zero and captured by the error term in the model. However, as a robustness check, we run the model by buffering the home ranges of the wolf pack home ranges by 1 km and 5 km to test the effects of wolf locations with varying sizes of estimated wolf pack home ranges.

The second measure of wolf presence used in the analysis is based on data collected on known instances of wolf depredation of livestock. If a rancher suspects that livestock has been injured or killed by wolves or other predators, they can request a WS investigation. We obtained all WS depredation investigation reports (not just wolf depredation investigations) conducted on sample ranches over the time period of the study. Thus, the second wolf measure is a latent variable defined as 1 if there was at least one WS confirmed wolf depredation on ranch *i* in year *t*, and zero otherwise. Given that our sample ranches did not have any confirmed or probable WS losses due to other predators such as bears, coyotes, or mountain lions, we have confidence that any potential effects associated with this measure were wolf effects and not other predator species.

Of the 18 ranches for which data were available, 10 ranches had a known wolf pack home range that overlapped the ranch's grazing allotment at some point during the 1995–2010 time period (treatment group), while 8 ranches never had a known wolf pack home range overlapping the ranch grazing allotments (control group). Table 1 provides the descriptive statistics for the treatment and control groups for each of the variables used in the study.

One important question for a study of this nature is whether the control (non-wolf) and treatment (wolf) groups are similar in observables. While the two groups did not appear to be substantially different with respect to observables, the simple difference-in-means were statistically significant for all of our observed variables, with the exception of two: hormone implanting and the length of the growing season (standard deviation of NDVI). Notably, both steer and heifer calves on treatment group ranches tended to be heavier than calves on control group ranches. The reasons for the differences were likely related to other observable characteristics that lead to greater weights, such as a greater number of days between birth and weaning or greater average precipitation. However, calf breed may also have played a role in the differences. The treatment group ranches had a higher proportion of Black Angus calves compared to the control group, and Black Angus calves tend to be, on average, heavier than other breeds in our sample.

The most pronounced difference in independent variables between the two groups was in the average number of calves, with treatment ranches having approximately twice as many calves on a ranch as control group ranches. Climatological variables that play an important role in habitat selection and forage quality, such as mean NDVI, the standard deviation of mean NDVI, snowfall, precipitation, and temperature, had smaller differences but were still statistically different between the two groups. These differences in means suggested that the control and treatment groups had important statistical differences that must be accounted for in estimation. Of course, if wolf activities on a ranch in a particular year, $\boldsymbol{w}_{\mathrm{it}}$, were truly random exogenous effects that were uncorrelated with e_{it}, the $\boldsymbol{\eta}$ coefficients provide consistent estimates of the effect of wolves on calf weight, regardless of observed differences in the two groups. Any additional information provided by observables simply improves the efficiency of the estimates.

Results

If all 18 ranches in the dataset were identical in every respect, except for wolf home range overlap and confirmed wolf depredations, then consistent estimates of wolf effects on calf weights would be obtained by a simplified version of equation (1) by regressing calf weight on a constant, the wolf overlap variable, and the wolf depredation variable. However, if ranches differ in important husbandry or environmental characteristics that also impact calf weight, then this simplified model that does not account for these characteristics may lead to inconsistent estimates of the wolf effects. In the regression results that follow, we began with the simplest regression, which assumed the treatment and control groups differed only in their exposure to wolf home ranges and depredations, and then added additional fixed effects and observable variables in subsequent regressions to control for important observable and unobservable characteristics. The differences in means for a number of important husbandry and climatological characteristics in table 1 suggested that these additional controls may

Table 1. Summary Statistics of Ranches with and without Wolf MCP Overlaps

	10 Ranches Where Wolf MCP's Do Overlap with the Ranch at Some Point in the Study					8 Ranches Where Wolf MCP's Do Not Overlap with the Ranch at Some Point in the Study				
Variable	Obs+	Mean	Std Dev	Min	Max	Obs+	Mean	Std Dev	Min	Max
Calf Weight (lbs)										
Total*	243	644	56	531	809	194	604	68	461	778
Steers*	134	665.73	49.844	543	809	92	629.45	67.796	478	778
Heifers*	109	617.32	50.74	531	749	102	581.82	60.732	461	713
Calf Age (days)*	243	248	34	191	343	194	231	30	160	347
# of Calves*	243	345	327	89	1,300	194	162	42	65	275
Mean NDVI*	243	140.9	7.2	128.1	163.5	194	138.7	5.6	125.2	152.1
Standard Deviation of NDVI	243	14.7	3.4	7.5	21.4	194	14.2	2.6	8.0	22.1
Annual Aggregate Precipitation (inches)*	243	16.8	6.0	6.0	33.1	194	15.4	4.9	6.6	26.7
Anunual Average Temperature (degrees F)*	243	42.5	3.5	35.3	48.7	194	44.6	1.7	40.1	49.3
Annual Aggregate Snowfall (inches)*	243	71.6	56.9	0.5	263.5	194	57.5	36.8	11.7	153.0
Hormone Implanting	243	0.35	0.48	0.00	1.00	194	0.34	0.47	0.00	1.00
Artificial Insemination (y/n)*	243	0.11	0.31	0	1	194	0.05	0.22	0	1
Ranch Overlaps MFWP Wolf Home Range (y/n)										
– all original MCPs and centroids*	243	0.31	0.4646	0	1	194	0.00	0	0	0
– all MCPs and centroids buffered by 1 km*	243	0.34	0.4738	0	1	194	0.00	0	0	0
– all MCPs and centroids buffered by 5 km*	243	0.45	0.4988	0	1	194	0.00	0	0	0
Wildlife Service Confirmed Wolf Depredation (y/n)*	243	0.04	0.1991	0	1	194	0.00	0	0	0
Range Riders (y/n)*	243	0.14	0.3476	0	1	194	0.00	0	0	0

Note: The * denotes that the difference in means between the two groups are statistically significant at the 5%level.

+Not all 18 ranches had calf weaning weight data for the full 16 year period from 1995–2010. Some ranches only had records from the late 1990's onward. Likewise, the on-ranch survey's were conducted June 2010 through March 2011. Those ranches that had on-ranch interviews in the summer of 2010 did not yet have thier 2010 weaning weight data. As a result, only 437 observations were available (rather than the full $18 \times 16 \times 2 = 576$ potential panel of observations).

Table 2. Wolf Home Range and Depredations on Calf Weight Regressions

	(1)	(2)	(3)	(4)	(5)	(6)
Ranch Overlaps MFWP Wolf Home Range	40.034***	43.266***	4.64	4.256	4.256	0.027
	(6.774)	(7.516)	(5.833)	(3.920)	(4.114)	
Wildlife Service Confirmed Wolf Depredation	−40.969***	−37.696***	−19.646*	−21.911**	−21.911**	−0.051
	(11.305)	(11.178)	(10.421)	(9.962)	(10.783)	
Steer				50.003***	50.003***	0.387
				(2.841)	(2.427)	
Calf Age (days)				0.338*	0.338*	0.175
				(0.181)	(0.193)	
Hormone Implanting				24.282***	24.282***	0.179
				(5.988)	(6.044)	
# of Calves				−0.067	−0.067	−0.271
				(0.059)	(0.067)	
Artificial Insemination				3.001	3.001	0.013
				(9.419)	(11.700)	
Mean NDVI				−1.029	−1.029	−0.106
				(0.976)	(1.035)	
Standard Deviation of NDVI				1.595	1.595	0.076
				(0.970)	(1.119)	
Annual Aggregate Precipitation (inches)				2.279***	2.279***	0.196
				(0.556)	(0.638)	
Anunual Average Temperature (degrees F)				2.974	2.974	0.140
				(2.435)	(2.788)	
Annual Aggregate Snowfall (inches)				−0.262***	−0.262***	−0.200
				(0.074)	(0.085)	
Range Riders				12.19	12.19	0.051
				(19.318)	(19.695)	
Constant	618.94					
	(3.503)					
Year Fixed Effects	no	yes	yes	yes	yes	
Ranch Fixed Effects	no	no	yes	yes	yes	
Breed Fixed Effects	no	no	no	yes	yes	
Errors	robust	robust	robust	robust	clustered	
Observations	437	437	437	437	437	
AIC	4,859	4,869	4,476	4,156	4,156	
R-squared	0.06	0.11	0.66	0.85	0.85	

Notes: Columns (1)–(4) report robust standard errors. Column (5) reports clustered errors, clustered on the ranch-year observation. Column (6) reports the standardized beta coefficients for the regression in column (5).
*significant at 10%; **significant at 5%; ***significant at 1%

be important for consistent estimation of the wolf effects.

In column (1) of table 2, the baseline regression model of equation (1) is estimated on the pooled sample using only the two wolf presence measures and a constant. The ranch overlap variable and the confirmed wolf depredation variable were both statistically significant but of opposite signs. While the negative coefficient on the wolf depredation variable is consistent with the hypothesis that wolf depredations have a negative effect on calf weight, the positive coefficient on the wolf home range overlap variable was counter-intuitive, but was explained in subsequent regressions by including additional covariates for calf weight. In column (2) of table 2, we included year dummies to control for any changing characteristics related to calf ranching in western Montana over time, and in column (3) we added ranch-specific fixed effects to control for unobserved ranch-specific geography and husbandry practices. While the inclusion of time fixed effects in column (2) had little effect, the inclusion of ranch fixed effects in column (3) had a substantial effect on both of the wolf measure coefficient estimates. When ranch fixed effects were included, the ranch overlap variable was no longer statistically significant, indicating that unobserved time-invariant characteristics of a ranch, such as ranch location and geography, are positively correlated with the types of places that wolves are likely to be found. However, the Wildlife Service confirmed that the wolf depredation variable remained negative and statistically significant, albeit at a smaller magnitude. The WS-confirmed wolf depredation estimate implies that for ranch-year observations where a confirmed wolf depredation has occurred, average calf weaning weights were 19.6 pounds lighter than what the same ranch would have experienced had a confirmed wolf depredation not occurred.

The regression in column (3) made it particularly clear that unobserved, time-invariant, ranch-level husbandry and geographic characteristics are important for explaining calf weights, and that wolf home ranges and depredations are correlated with these unobserved characteristics. This is not surprising since many of the unobserved geographic characteristics that make for good ranching locations may also be locations that are favorable in terms of being attractive wolf habitat. For example, in table 1, ranches overlapping with wolves had slightly higher forage, as indexed by NDVI, cooler temperatures, and greater precipitation and snowfall than ranches that never overlapped with wolf home ranges. As long as these characteristics remain fairly constant over time, then econometrically this was not a problem for consistent estimation of our wolf variables, as these factors were controlled for by the ranch fixed effects. If, however, the time-variant factors were also correlated with wolf locations or depredations, then the wolf home range overlap and depredation estimates may be inconsistent.

In column (4) of table 2, we included all other observable time-variant ranch husbandry and spatial environmental variables that may affect calf weight across ranches. We find that the steer dummy variable, the number of calves on a ranch,[22] hormone implanting, and annual precipitation were all positive and statistically significant determinants of calf weight, while annual aggregate snowfall had a statistically significant negative impact on calf weight. The estimates on wolf home range and wolf depredations remained similar to column (3), with the statistical significance of the wolf depredation coefficient increasing with the improved efficiency of the model. As evidenced by the increase in the R^2 and the falling AIC, the model in column (4) explained the largest variation in calf weight with the best fit to the data when compared to the models in columns (1) through (3).

In column (5), we recognized that the errors associated with steer and heifer observations on a ranch in a particular year were likely to be correlated and could lead to an overestimation of the *t*-statistics (Bertrand, Duflo, and Mullainathan 2004), so the errors were clustered on the ranch-year observation. Although the standard errors increased slightly, the statistical significance of the results was unchanged relative to the robust standard errors in column (4).

In column (6), we report the standardized beta coefficients for the regression results in column (5). While we must be careful about interpretations of the standardized beta coefficients on dummy variables such as the WS wolf depredation variable or hormone implanting, the standardized beta coefficients can be instructive for understanding the relative importance of wolf depredations on variations in calf weight when compared to other significant husbandry and climatological factors. Although the marginal effect of wolf depredations was statistically significant and economically meaningful in columns (1) through (5), the beta coefficients in column (6) indicate that the magnitude of standard deviation changes in wolf depredations are relatively small when compared to other factors that affect calf weight. This is particularly true when the standardized beta coefficient on wolf depredation is compared to standardized beta coefficients on some of the climatological factors or observable husbandry practices. A one standard deviation change in wolf depredations decreased calf weight by 0.05 standard deviations, while a standard deviation change in hormone implanting, age of the calf at weaning, annual precipitation, and annual snowfall, all impacted calf weight by between 0.18 and 0.20 standard deviations. This indicated that, although wolf depredations had a statistically significant effect on calf weight across the herd, the relative importance of this variable in explaining overall variation in calf weights is an order of magnitude smaller than standard deviation

[22] Given that we controlled for ranch size using ranch-specific fixed effects, the number of calves should capture net stocking density and herd size effects. To be certain, we ran additional robustness regressions explicitly controlling for stocking density (defined as the number of calves per acre) in addition to the number of cow-calf pairs, but found no statistical significance to the separate stocking density variable, and no change to the results reported in the paper.

Table 3. Robustness Tests

	(1)	(2)	(3)	(4)	(5)
Ranch Overlaps MFWP Wolf Home Range					
– all original MCPs and centroids		2.85 (4.149)			2.793 (4.146)
– all MCPs and centroids buffered by 1 km			2.912 (4.146)		
– all MCPs and centroids buffered by 5 km				6.216 (3.987)	
Wildlife Service Confirmed Wolf Depredation[a]	−20.361* −10.932				4.671 (8.513)
Steer	49.954*** (2.428)	50.050*** (2.423)	50.050*** (2.423)	50.057*** (2.416)	50.126*** (2.438)
Calf Age (days)	0.340* (0.193)	0.342* (0.191)	0.343* (0.191)	0.341* (0.190)	0.340* (0.192)
Hormone Implanting	24.692*** (6.031)	24.139*** (6.012)	24.203*** (5.991)	24.358*** (5.933)	24.079*** (6.037)
# of Calves	−0.066 (0.067)	−0.066 (0.068)	−0.066 (0.068)	−0.065 (0.068)	−0.067 (0.068)
Artificial Insemination	2.634 (11.673)	1.942 (11.593)	1.96 (11.600)	3.511 (12.050)	1.731 (11.576)
Mean NDVI	−0.988 (1.026)	−1.02 (1.035)	−1.016 (1.035)	−1.051 (1.043)	−0.998 (1.043)
Standard Deviation of NDVI	1.635 (1.117)	1.648 (1.109)	1.667 (1.108)	1.616 (1.102)	1.628 (1.113)
Annual Aggregate Precipitation (inches)	2.201*** (0.633)	2.202*** (0.657)	2.201*** (0.656)	2.073*** (0.668)	2.202*** (0.657)
Anunual Average Temperature (degrees F)	3.026 (2.786)	4.288* (2.527)	4.261* (2.526)	4.248* (2.528)	4.371* (2.531)
Annual Aggregate Snowfall (inches)	−0.254*** (0.086)	−0.242*** (0.088)	−0.241*** (0.087)	−0.233*** (0.087)	−0.239*** (0.088)
Range Riders	14.905 (19.535)	12.207 (19.931)	12.231 (19.975)	10.315 (20.231)	12.602 (20.068)
Breed Fixed Effects	yes	yes	yes	yes	yes
Ranch Fixed Effects	yes	yes	yes	yes	yes
Year Fixed Effects	yes	yes	yes	yes	yes
Errors	clustered	clustered	clustered	clustered	clustered
Observations	437	437	437	437	437
AIC	4,155	4,159	4,159	4,157	4,161
R-squared	0.85	0.85	0.85	0.85	0.85

Note: Columns (1)-(5) report clustered errors, clustered on the ranch-year observation.
[a]Original confirmed wolf depredation variable used in columns (1)–(4); placebo variable used in column (5).
*significant at 10%; **significant at 5%; ***significant at 1%

changes in other important husbandry and climatological factors.

In table 3, we conducted a number of robustness tests related to the wolf measures. Due to the strong correlation between the wolf home range variable and the confirmed wolf depredation variable, we estimated the model in column (1) with only the WS-confirmed wolf depredation variable, and in column (2) with only the wolf home range variable. The results are unchanged from table 1. In columns (3) and (4), we tested alternative measures of wolf home range size. As mentioned above, the original wolf home range data were MCPs (measured by connecting the outermost observations on a wolf pack) and centroids. It is possible that the MCPs and centroids may underestimate the true range of wolf packs on the landscape. To test the robustness of the wolf pack home range effect, in columns (3) and (4) we buffered the original MCPs and centroids around the edges by 1 km and 5 km to test for more liberal interpretations of wolf pack home ranges. However, this did not change the results when using the original MCP and centroid data. Ranches with wolf-pack home-ranges overlapping their grazing allotments still had no statistically significant effects on calf-weights.[23]

In column (5) of table 3, we estimated the effects of a placebo variable to test the robustness of the WS-confirmed wolf depredation variable. For the placebo variable, we randomly selected 10 observations (the same number of wolf depredation observations confirmed by WS in the original dataset) as our placebo observations and re-estimated the same regression as in column (5) of table 2 to test whether the wolf depredation variable was simply picking up other random correlations in the data. The coefficient on the placebo WS-confirmed wolf depredation variable was positive and statistically insignificant, providing additional assurance that the WS-confirmed wolf depredation variable picked up the effects of wolf depredations on calf weight and not some other unobserved random correlation related to that variable.

Discussion

Our results indicate that the economic significance of wolf kills on calf weight will be realized in the form of lost revenue on calf sales for affected ranches. The majority of western Montana calf producers sell their calves as feeder cattle by the pound. If ranches that experience at least one wolf depredation also experience a decrease in calf weaning weights, then the total economic impact of the depredation(s) could be more substantial than the cost of the injury or death loss alone. In our sample, the average ranch had 264 calves with a weaning (sale) weight of 626 pounds per calf. In November of 2010, the average selling price of calves in Montana was $1.15 per pound (USDA 2010). Thus, the results of our study imply that a confirmed wolf kill on a ranch decreases the average weight of calves by approximately 22 pounds, or 3.5%. While the magnitude of this effect may not appear exceptionally large, it is economically meaningful for the affected ranches. At $1.15 per pound, a 22 pound loss in weight across a 264 calf herd implies a loss in revenues at sale of $6,679 for the average rancher in the sample. When one considers that the average compensation payment for confirmed cattle lost to direct depredation is approximately $900, the uncompensated indirect losses are nearly 7.5 times the direct losses of cattle depredation to wolves.

To put these losses into a broader context, we consider some simple calculations of the indirect costs of wolf depredation on calf weights in western Montana based on 2011 statistics. In 2011, the WS confirmed that 65 cattle in Montana were killed by wolves, with another 18 that were classified as probable wolf kills. These kills occurred on 37 different ranches. If we assume that the average ranch operation in the population was identical in all characteristics to the average ranch in our sample, then at $1.15 per pound, the estimated aggregate effect on western Montana cattle production could be a loss of $247,130.

To put these estimates into context, consider that in 2011, the Montana Livestock Loss Reduction and Mitigation Board (LLRMB) paid $75,389 to Montana ranchers for 83 cattle that were confirmed or probable wolf predations.[24] Given the estimates above, the indirect costs of wolf predation on cow-calf ranches may potentially be 3 to 4 times greater than what the LLRMB is currently paying for all livestock killed by wolf predation. It is clear that the uncompensated indirect economic losses through lower calf weaning weights from wolf depredation are potentially substantial when compared to the compensated direct losses from depredation. However, these simple calculations should be taken with a degree of caution, as the total losses to ranchers is dependent on the actual number of calves sold by each producer, the going market price at which the calves are sold, and the number of ranches that are affected by at least one WS-confirmed wolf depredation.

While our results indicate that the potential uncompensated losses due to depredation can be economically meaningful for affected ranches, they also emphasize that the amount of variation in calf weight due to wolf effects is relatively small when compared to other

[23] In addition to buffering the wolf pack home ranges by 1 km and 5 km, we also tested wolf pack home ranges in a variety of different ways, including dropping the centroid packs, interacting wolf packs with the number of known wolves in a pack, and expanding actual MCPs to average wolf pack territory sizes. These results are not presented here, as all variations produce the same result of no statistically significant effects of wolf home range on calf-weight.

[24] http://liv.mt.gov/LLB/lossdata.mcpx

important factors such as ranch-specific effects and changes in climatological factors. Indeed, the explanatory power of the two wolf variables in column (1) of table 2 explained a maximum of 6% (as evidenced by the R^2 of the model) of the variance in calf weight across all ranches in our sample. In contrast, it was evident that when ranch fixed effects were included in column (3) of table 2, time-invariant ranch-specific factors such as geography and husbandry practices explained a large degree of the variation in calf weights. The model explained 66% of the variation in calf weight and 85% of the variation when all other covariates (including ranch and year-specific effects) were included in column (5). Further, in comparison to the effects of wolf depredation, the beta coefficients in column (6) of table 2 emphasized that precipitation and winter snowfall are the most important climatic effects driving calf weight in Montana. We also found that male calves (steers) were, on average, 50 pounds heavier than heifers, and this effect represented an 8% average difference. This is comparable in magnitude to previous studies on sex-differences in calf weight gain, which showed 5%–7% differences (Beffa, van Wyk, and Erasmus 2009; Hanawalt 2011) in weight between steer and heifer calves. Finally, calf age influenced weight gain by an average of 0.34 pounds/day, which was a bit smaller in magnitude, but still similar to previous studies estimates of 1.2 to 1.47 pounds per day (Botkin and Whatley 1953; Koger and Knox 1945; and Minyard and Dinkel 1965). Thus, while the main focus of our study was to test for wolf-specific effects on calf weight gain, our results on the non-wolf effects are consistent with previous studies, and show that a substantial amount of variation in calf weight is explained in Montana by ranch-specific husbandry and climatological factors. These results also suggest that individual ranchers may, in the event of confirmed wolf depredation, offset potential indirect losses through improvements to husbandry practices (e.g., Muhly et al. 2010), which we have shown explain a substantially higher proportion of calf weight differences than wolf depredation effects.

Whether or not wolves have similar indirect effects on wild ungulates is also an important ecological and economic question. Wild ungulates such as deer and elk are important for economic development in rural states, and generate tourism and hunting revenues for the state and local businesses (Skonhoft 2006). Preliminary evidence suggested that predation risk by wolves may have been correlated with decreasing pregnancy rates in wild elk (Creel et al. 2007), but follow up studies have failed to find any consistent effect of wolf predation on wild ungulate body condition, pregnancy, or calf recruitment (White et al. 2011; Middleton et al. 2013). This is perhaps to be expected in wild ungulates that have undergone a close evolutionary history with wolves (Boonstra 2013). Recent comparative studies of the effects of wolves on cattle and elk, for example, show that cattle have exaggerated anti-predatory behavior, reduce their foraging, increase vigilance, and increase movement rates for longer after exposure to wolf predation risk than wild elk (Laporte et al. 2010; Muhly et al. 2010). Thus, while the indirect economic costs of wolf depredations on cattle weight is found in this study, similar indirect economic costs of wolf predation on wild ungulates cannot be inferred.

Conclusion

The public debate over wolves and their impact on ecosystems and society is not likely to end soon. There is still much that we need to learn about wolves and their interactions with both wild and domestic animals to understand the true net costs and benefits of wolves on the natural landscape. Wildlife management and any public programs designed to compensate for losses generated by wolves or other predatory species require the best available science and information to make effective policy decisions. In this paper, we focus on one important component of wolf conflict with domestic livestock that has not been previously studied. Specifically, we determine the reduced form indirect effects of wolf home range locations and Wildlife Services-confirmed wolf depredations on domestic calf weight in Montana.

Using a quasi-experimental approach with panel data from 18 ranches in western Montana, combined with spatial data on wolf locations and satellite generated climatological data, we found that ranches with wolf home ranges that overlap ranch pasturing areas had no statistically significant effect on calf weights on those ranches. However, on ranches where a wolf has been confirmed to have killed cattle, there were statistically significant negative effects on the calf weights of the herd. Specifically, the average calf weight declined by 3.5%, or 22 pounds, on ranches in the year that they experienced a confirmed wolf depredation. For the average ranch in our sample, this translated into a $6,679 loss across the herd at the time of calf sale. Although this may not seem like a large loss, it is not economically insignificant. Given that the average compensation for a wolf depredation is $900 per cow, the uncompensated estimated indirect loss for the average ranch was approximately 7.5 times the compensated loss.

From a policy perspective, this implies that economic efficiencies may be gained by subsidizing or supporting mitigation efforts in areas where cattle losses due to wolf depredation are documented. Further, this work demonstrates the importance of careful micro-level analysis on how species reintroduction under the ESA may conflict with economic development goals. Given the importance of funding for successful recovery efforts and the potential influence that conflicts with economic development can have for funding decisions, a more complete knowledge of the sources of conflict is necessary at the species level for effective policy in the future. This study has identified a particular form of indirect conflict with economic development from wolf reintroduction that has not previously been studied or measured. To the extent that other predatory endangered species are reintroduced in the future, a complete understanding of their impacts on society will be necessary to design effective recovery plans and funding mechanisms. Indeed, the success of the recovery effort and public and industry support will hinge on these factors. For future wolf-related policy, determining which mitigation strategies or potential compensation schemes may be most effective will require more detailed research into the exact mechanisms (inefficient foraging, stress to the mother cow, etc.) by which calf weight is reduced. The reduced form estimates in this paper highlight the indirect ways in which species recovery can create conflict with economic development, but cannot answer the more detailed biological questions. The exact biological mechanisms through which wolves affect cattle, as well as potential husbandry or policy responses to those mechanisms, should be an important area of future research.

References

Alderman, J.H. 2006. Scared Skinny: Ranchers Say Fear of Wolves Causing Livestock to Lose Weight. Available at: http://missoulian.com/business/scared-skinny-ranchers-say-fear-of-wolves-causing-livestock-to/article_ce7394f9-e5fb-52e1-9985-6202b835703f.html. Accessed November 18, 2013.

Alderton, B.W., Hixon, D.L., Hess, B.W., Woodard, L.F., Hallford, D.M., and Moss, G.E. 2000. Effects of Supplemental Protein Type on Productivity of Primiparous Beef Cows. *Journal of Animal Science* 78: 3027–3035.

Alt, K.L., Frisina, M.R., and King, F.J. 1992. Coordinated Management of Elk and Cattle, a Perspective: Wall Creek Wildlife Management Area. *Rangelands* 14 (1): 12–15.

Altendorf, K.B., Laundre, J.W., Lopez Gonzalez, C.A., and Brown, J.S. 2001. Assessing Effects of Predation Risk on Foraging Behavior of Mule Deer. *Journal of Mammalogy* 82 (2): 430–439.

Animal and Veterinary: NADA 141-043 Synovex Plus - origional approval. 2009. Available at: http://www.fda.gov/AnimalVeterinary/Products/ApprovedAnimalDrugProducts/FOIADrugSummaries/ucm116149.htm. Accessed June 29, 2011.

Azzam, S.M., Kinder, J.E., Nielsen, M.K., Werth, L.A., Gregory, K.E., Cundiff, L.V., and Koch, R.M. 1993. Environmental Effects on Neonatal Mortality of Beef Calves. *Journal of Animal Science* 71: 282–290.

Background on Defenders of Wildlife Wolf Compensation Trust. 2011. Available at: http://www.defenders.org/programs_and_policy/wildlife_conservation/solutions/wolf_compensation_trust/background.php.

Baker, P.J., Boitani, L., Harris, S., Saunders, G., and White, P.C.L. 2008. Terrestrial Carnivores and Human Food Production: Impact and Management. *Mammal Review* 38: 123–166.

Barlow, R., Belinda Dettmann, E., and Williams, L.G., 1978. Factors Affecting Pre-weaning Growth and Weaning Conformation of Angus Cattle. *Australian Journal of Animal Science* 29: 359–371.

Bednekoff, P.A., and Ritter, R. 1994. Vigilance in Nxai Pan Springbok, Antidorcas Marsupialis. *Behaviour* 129 (1): 1–11.

Beffa, L.M., J.B van Wyk, and Erasmus, G.J. 2009. Long-term Selection Experiment with Afrikaner Cattle 1. Environmental Factors Affecting Calf Growth Traits. *South African Journal of Animal Science* 39 (2): 89–97.

Boonstra, R. 2013. Reality as the Leading Cause of Stress: Rethinking the Impact of Chronic Stress in Nature. *Functional Ecology* 27 (1): 11–23.

Botkin, M.P., and Whatley, J.A. 1953. Repeatability of production in range beef cows. *Journal of Animal Science* 12: 552–560.

Boyd, D.K., Paquet, P.C., Donelson, S., Ream, R.R., Pletscher, E.H. and White, C.C. 1995. Dispersal characteristics of a colonizing wolf population in the Rocky Mountains. In *Ecology and conservation of wolves in a changing world*, ed. Carbyn, L.N., S.H. Fritts, and D.R Seip, 135–140. University of Alberta, Edmonton: Canadian Circumpolar Institute.

Bradley, E.H., and Pletscher, D.H. 2005. Assessing factors related to wolf depredation of cattle in fenced pastures in Montana and Idaho. *Wildlife Society Bulletin* 33 (4): 1256–1265.

Bradley E.H., Pletscher, D.H., Bangs, E.E., Kunkel, K.E., Smith, D.W., Mack, C.M., Meier, T.J., Fontaine, J.A., Niemeyer, C.C., and Jimenez, M.D. 2005 Evaluating wolf translocation as a nonlethal method to reduce livestock conflicts in the northwestern United States. *Conservation Biology* 19: 1498–1508.

Breck, S., and Meier, T. 2004. Managing wolf depredation in the United States: past, present, and future. *Sheep and Goat Research Journal* 19: 41–46.

Brown, J.E., Brown, C.J., and Butts, W.T. 1972. Relationships among weights, gains and earliness of maturing in hereford and angus females. *Journal of Animal Science* 35: 507–517.

Brown, J.S. 1988. Patch use as an indicator of habitat preference, predation risk, and competition. *Behavioral Ecology and Sociobiology* 22 (1): 37–47.

Brown, J.S., and Morgan, R.A. 1995. Effects of foraging behavior and spatial scale on diet selectivity: a test with fox squirrels. *Oikos* 74 (1): 122–136.

Brown, J.S., Kotler, B.P., Smith, R.J., and Wirtz II, W.O. 1988. The effects of owl predation on the foraging behavior of heteromyid rodents. *Oecologia* 76 (3): 408–415.

Burgess, J.B., Landblom, N.L., and Stonaker, H.H. 1954. Weaning weights of hereford calves as affected by inbreeding, sex, and age. *Journal of Animal Science* 13: 843–851.

Burroughs, W., Culbertson, C.C., Cheng, E., Hale, W.H., and Homeyer, P. 1955. The Influence of Oral Administration of Diethylstilbestrol to Beef Cattle. *Journal of Animal Science* 14: 1015–1024.

Busch, J. and Cullen, R. 2009. Effectiveness and cost-effectiveness of yellow-eyed penguin recovery. *Ecological Economics* 68: 762–776.

Cooperative Observer Program Fact Sheet. 2010. Available at: http://www.nws.noaa.gov/om/coop/Publications/coop_factsheet.pdf.

Creel, S., Christianson, D., Liley, S., and Winnie, J.A. 2007. Predation Risk Affects Reproductive Physiology and Demography of Elk. *Science* 315 (5814): 960.

Cundiff, L.V., Willham, R.L., and Pratt, C.A. 1966. Effects of certain factors and their two-way interaction on weaning weight in beef calves. *Journal of Animal Science* 25: 972–982.

Dadi, H., Schoeman, S.J., Jordaan, G.F., and van der Westhuizen, J. 2002. The influence of Charolais and Angus breeding levels on pre-weaning growth performance traits in corssbred calves. *South African Journal of Animal Science* 32 (3): 201–207.

Dal Zotto, R., Penasa, M., De Marchi, M., Cassandro, M., Lopez-Villalobos, N., and Bittante, G. 2009. Use of crossbreeding with beef bulls in dairy herds: effect on age, body weight, price, and market value of calves sold at livestock auctions. *Journal of Animal Science* 87: 3053–3059.

Dawson, D., and Shogren, J.F. 2001. An Update on Priorities and Expenditures under the Endangered Species Act. *Land Economics* 77 (4): 527–532.

Dietz, R.E., Hall, J.B., Whittier, W.D., Elvinger, F., and Eversole, D.E. 2003. Effects of feeding supplemental fat to beef cows on cold tolerance in newborn calves. *Journal of Animal Science* 81: 885–894.

Dimius, D.A., Goering, H.K., Oltjen, R.R., and Rumsey, T.S. 1976. Finishing steers on alfalfa hay or meal and additives. *Journal of Animal Science* 43: 319.

Doren, P.E., Long, C.R., and Cartwright, T.C. 1986. Factors affecting the relationship between calving interval of cows and weaning weights of calves. *Journal of Animal Science* 62: 1194–1202.

Elgar, M.A. 1989. Predation vigilance and the group size in mammals and birds: a critical review of the empirical evidence. *Biological Reviews of the Cambridge Philosophical Society* 64: 13–33.

Embry, I.B., and Gates, R.N. 1976. Diethylstilbestrol, Zeranol or Synovex implants for finishing steers. *Journal of Animal Science* 43: 320.

Fernandez-Rivera, S., Lewis, M., Klopfenstein, T.J., and Thompson, T.L. 1989. A simulation model of forage yield, quality and intake and growth of growing cattle grazing cornstalks. *Journal of Animal Science* 67; 581–589.

Ferraro, P., C. McIntosh, and Ospina, M. 2007. The effectiveness of the US endangered species act: An econometric analysis using matching methods. *Journal of Environmental Economics and Management* 54: 245–261.

Frequently Asked Questions about the Wolf Compensation Trust. 2011. Available at: http://www.defenders.org/programs_and_policy/wildlife_conservation/solutions/wolf_compensation_trust/frequently_asked_questions.php.

Gilliam, J.F., and Fraser, D.F. 1987. Habitat selection under predation hazard: test of a model with foraging minnows. *Ecology* 68 (6): 1856–1862.

Greenstone, M. and Gayer, T. 2009. Quasi-experimental and experimental approaches to environmental economics. *Journal of Environmental Economics and Management* 57: 21–44.

Gregory, K.E., Swiger, L.A., Koch, R.M., Sumption, L.J., Rowden, W.W., and Ingalls, J.E. 1965. Heterosis in preweaning traits of beef cattle. *Journal of Animal Science* 24: 21–28.

Harper, E.K., Paul, W.J., and Mech, L.D. 2005. Causes of wolf depredation increase in Minnesota from 1979-1998. *Wildlife Society Bulletin* 33 (3): 888–896.

Havstad, K.M., McInerney, M.J., and Church, S.B. 1989. Growth patterns of range beef calves over discrete preweaning intervals. *Canadian Journal of Animal Science* 69: 865–869.

Hebblewhite, M., Merrill, E. and McDermid, G. 2008. A multi-scale test of the forage maturation hypothesis in a partially migratory ungulate population. *Ecological Monographs* 78: 141–166.

Hebblewhite, M. 2011. Unreliable knowledge about economic impacts of large carnivores on bovine calves. *Journal of Wildlife Management* 75: 1724–1730.

Hebblewhite, M., and Smith, D.W. 2011. Wolf community ecology: ecosystem effects of recovering wolves in Banff and Yellowstone National Parks. In *The world of wolves: new perspectives on ecology, behavior, and policy*, ed. M. Musiani, L. Boitaini, and P.C. Paquet. University of Calgary Press, Calgary, AB.

Heinemann, W.W., and Van Keuren, R.W. 1962. Effects of Progesterone Estradiol implants, grain feeding and kinds of irrigated pastures on steer performance and carcass quality. *Journal of Animal Science* 21: 611–614.

Hetzel, D.J., Mackinnon, M.J., Dixon, R., and Entwistle, K.W. 1989. Fertility in a tropical beef herd divergently selected for pregnancy rate. *Animal Production* 49: 73–81.

Hobbs, N.T., Henrik, A., Persson, J., Aronsson, M., and Chapron, G. 2012. Native predators reduce harvest of reindeer by Sami pastoralists. Ecological Applications 22 (5): 1640–1654.

Holechek, J.L. 1980. Concepts concerning forage allocation to livestock and big game. *Rangelands* 2 (4): 158–159.

Howery, L.D., and DeLiberto, T.J. 2004. Indirect effects of carnivores on livestock foraging behavior and production. *Sheep and Goat Research Journal* 19: 53–57.

Hunt, D.W., Henricks, D.M., Skelley, G.C., and Grimes, L.W. 1991. Use of trenbolone acetate adn estradiol in intact adn castrate male cattle: effects on growth, serum hormones, and carcass characteristics. *Journal of Animal Science* 69: 2452–2462.

Hunter, L.T., and Skinner, J.D. 1998. Vigilance behaviour in African ungulates: the role of predation pressure. *Behaviour 135* (2): 195–211.

Kahl, S., Bitman, J., and Rumsey, T.S. 1978. Effect of Synovex-S on growth rate and plasma thyroid hormone concentrations in beef cattle. *Journal of Animal Science* 46: 232–237.

Kamal, T.H., and Johnson, H.D. 1971. Total body solids loss as a measure of a short-term heat stress in cattle. *Journal of Animal Science* 32: 306–311.

Kamal, T.H., and Seif, S.M. 1969. Effect of natural and controlled climates of the Sahara on virtual trituim space in Friesians and Water Buffaloes. *Journal of Dairy Science* 52: 1657.

Kerkvliet, J. and Langpap, C. 2007. Learning from endangered and threatened species recovery programs: A case study using U.S. Endangered Species Act recovery scores. *Ecological Economics* 63: 499–510.

Kie, J.G., Baldwin, J.A., and Evans, C.J. 1996. CALHOME: a program for estimating animal home ranges. *Wildlife Society Bulletin* 24 (2): 342–344.

Kluever, B.M., Breck, S.W., Howery, L.D., Krausman, P.R., and Bergman, D.L. 2008. Vigilance in cattle: the influence of predation, social interactions, and environmental factors. *Rangeland Ecology and Management* 61 (3): 321–328.

Koger, M., and Knox, J.H. 1945. A method for estimating weaning weights of range calves at a constant age. *Journal of Animal Science* 4: 285–290.

Kotler, B.P., and Holt, R.D. 1989. Predation and competition: the interaction of two types of species interactions. *Oikos* 54 (2): 256–260.

Kotler, B.P., Brown, J.S., and Hasson, O. 1991. Factors affecting gerbil foraging behavior and rates of owl predation. *Ecology* 72 (6), 2249–2260.

Kotler, B.P., Gross, J.E., and Mitchell, W.A. 1994. Applying patch use to asess aspects of foraging behavior in Nubian ibex. *The Journal of Wildlife Management 58*(2), 229–307.

de Knegt, H.J., Hengeveld, G.M., van Langevelde, F., de Boer, W.F., and Kirkman, K.P. 2007. Patch density determines movement patterns and foraging efficiency of large herbivores. *Behavioral Ecology* 18 (6): 1065–1072.

Lagory, K.E. 1986. Habitat, group size, and behaviour of white-tailed deer. *Behaviour 98* (1): 168–179.

Langpap, C. and Kerkvliet, J. 2010. Allocating Conservation Resources Under The Endangered Species Act. *American Journal of Agricultural Economics* 92 (1): 110–124.

Laporte, I., T.B. Muhly, J.A. Pitt, M. Alexander, and Musiani, M. 2010. Effects of wolves on elk and cattle behaviors: Implications for livestock production and wolf conservation. *PLoS ONE* 5.

Laster, D.B., Glimp, H.A., and Gregory, K.E. 1972. Age and weight at puberty and conception in different breeds and breedcrosses of beef heifers. *Journal of Animal Science* 34: 1031–1036.

Laundre, J.W., Hernandez, L., and Altendorf, K.B. 2001. Wolves, elk, and bison: reestablishing the "landscape of fear" in Yellowstone National Park, U.S.A. *Canadian Journal of Zoology* 79: 1401–1409.

Lima, S.L. 1995. Back to the basics of antipredatory vigilance: the group-size effect. *Animal Behaviour* 49: 11–20.

MacArthur, R.H., and Pianka, E.R. 1966. On optimal use of a patchy environment. *The American Naturalist* 100: 603–609.

MacGregor, R.G., and Casey, N.H. 2000. The effects of maternal calving date and calving interval on growth performance of beef calves. *South African Journal of Animal Science* 30 (1): 70–76.

MacNeil, M.D. 2003. Genetic evaluation of an index of birth weight and yearling weight to improve efficiency of beef production. *Journal of Animal Science* 81: 2425–2433.

Marlowe, T.J., and Gaines, J.A. 1958. The influence of age, sex, and season of birth of calf, and age of dam on preweaning growth rate and type score of beef calves. *Journal of Animal Science* 17: 706–713.

McCormick, W.C., Southwell, B.L., and Warwick, E.J. 1956. Factors affecting performance in herds of purebred and grade polled Hereford cattle. *Georgia Agricultural Experiment Station Technical Bulletin*.

Mech, L.D. 1970. The wolf: the ecology and behavior of an endangered species. Garden City, NY: National History Press.

Mech, L.D. 1996. A new era for carnivore conservation. *Wildlife Society Bulletin* 24 (3): 397–401.

Metrick, A. and Weitzman, M.L. 1996. Patterns of Behavior in Endangered Species Preservation. *Land Economics* 72 (1): 1–16.

Middleton, A.D., Kauffman, M.J., McWhirter, D.E., Jimenez, M.D., Cook, R.C., Cook, J.G., Albeke, S.E., Sawyer, H., and

White, P.J. 2013. Linking anti-predator behaviour to prey demography reveals limited risk effects of an actively hunting large carnivore. *Ecology Letters* doi:10.1111/ele.12133.

Minyard, J.A., and Dinkel, C.A. 1965. Weaning weight of beef calves as as affected by age and sex of calf and age of dam. *Journal of Animal Science* 24: 1067–1071.

Mohr, C.O. 1947. Table of equivalent populations of North American small mammals. *American Midland Naturalist* 37 (1): 223–249.

Montana State Legislature. 2009. *Montana Code Annotated 2-15-3112: Additional powers and duties of livestock loss reduction and mitigation board.* Available at: http://data.opi.mt.gov/bills/mca/2/15/2-15-3113.htm.

Moulton, Brent R., 1990. An Illustration of a Pitfall in Estimating the Effects of Aggregate Variables on Micro Units. Review of Economics and Statistics, 72(2), 334–338.

Muhly, T.B., and Musiani, M. 2009. Livestock depredation by wolves and the ranching economy in the Northwestern US. *Ecological Economics* 68 (8–9): 2439–2450.

Muhly, T., Gates, C.C., and Musiani, M. 2010. Husbandry practices reduce wolf depredation risk in southwestern Alberta, Canada. In The World of Wolves: new perspectives on ecology, behaviour and management. M. Musiani, L. Boitani, and P.C. Paquet (eds). University of Calgary Press, Calgary, AB. 261–286.

Muhly, T.B., Alexander, M., Boyce, M.S., Creasey, R., Hebblewhite, M., Paton, D., et al. 2010. Differential risk effects of wolves on wild versus domestic prey have consequences for conservation. *Oikos* 119: 1243–1254.

Musiani, M., T. Muhly, C.C. Gates, C. Callaghan, M.E. Smith, and E. Tosoni, 2005. Seasonality and reoccurrence of depredation and wolf control in western north america. *Wildlife Society Bulletin* 33: 876–887.

Mysterud, A., Langvatn, R., Yoccoz, N.G. and Stenseth, N.C. 2002. Large-scale habitat variability, delayed density effets on red deer populations in Norway. *Journal of Animal Ecology* 71: 569–580.

Naughton-Treves, L., Grossberg, R., Treves, A. 2003. Paying for tolerance: Rural citizens' attitudes toward wolf depredation and compensation . *Conservation Biology* 17 (6): 1500–1511.

Nelms, G.E., and Bogart, R. 1956. The effect of birth weight, age of dam and time of birth on suckling gains of beef calves. *Journal of Animal Science* 15: 662–666.

Oakleaf, J.K., Mack, C., and Murray, D.L. 2003. Effects of wolves on livestock calf survival and movements in central Idaho. *The Journal of Wildlife Management* 67 (2), 299–306.

Pettorelli, N., Pelletier, F., von Hardenberg, A., Festa-Bianchet, M. and Cote, S.D. 2007. Early onset of vegetation growth vs. rapid green-up impacts on juvenile mountain ungulates. *Ecology* 88, 381–390.

Pettorelli, N., Vik, J. Ol, Mysterud, A., Gaillard, J.M., Tucker, C.J. and Stenseth, N.C. 2005. Using the satellite-derived NDVI to assess ecological responses to environmental change. *Trends in Ecology and Evolution* 20, 503–510.

Pettorelli, N., Weladji, R.B., Holand, O., Mysterud, A., Breie, H. and Stenseth, N.C. 2005. The relative role of winter and spring conditions: linking climate and landscape-scale plant phenology to alpine reindeer body mass. *Biology Letters* 1, 24–26.

Power, T.M., and Barrett, R.N. 2001. *Post-cowboy economics: Pay and prosperity in the new American west.* Washington DC: Island Press.

Radunz, A.E., Fluharty, F.L., Day, M.L., Zerby, H.N., and Loerch, S.C. 2010. Prepartum dietary energy source fed to beef cows: I. effects on pre- and postpartum cow performance. *Journal of Animal Science* 88: 2717–2728.

Ream, R.R., Fairchild, M.W., Boyd, D.K., and Blakesley, A.J. 1989. First wolf den in western U.S. recent history. *Northwestern Naturalist* 70: 39–40.

Remote Sensing Phenology: NDVI from AVHRR. 2011. U.S. Department of the Interior, U.S. Geological Survey. Available at: http://phenology.cr.usgs.gov/ndvi_avhrr.php.

Remote Sensing Phenology: NDVI the foundation for Remote Sensing Phenology. 2011. U.S. Department of the Interior: U.S. Geological Survey. Available at: http://phenology.cr.usgs.gov/ndvi_foundation.php.

Remote Sensing Phenology: NDVI from AVHRR. 2011. Available at: http://phenology.cr.usgs.gov/ndvi_avhrr.php.

Remote Sensing Phenology: NDVI the foundation for Remote Sensing Phenology. 2011. http://phenology.cr.usgs.gov/ndvi_foundation.php.

Riley, S.J., Nesslage, G.M. and Maurer, B.A. 2004 Dynamics of early wolf and cougar eradication efforts in Montana: implications for conservation. *Biological Conservation*, 119(4), 575–579.

Rinehart, L. 2006. *Cattle production: considerations for pasture-based beef and dairy producers.* ATTRA-National Sustainable Agriculture Information Service.

Robbins, P. 2006. The Politics of Barstool Biology: Environmental Knowledge and Power in Greater Northern Yellowstone. *Geoforum* 37 (2): 185–199.

Rollins, W.C., and Guilbert, H.R. 1954. Factors affecting growth of beef calves during the suckling period. *Journal of Animal Science* 13: 517–527.

Rumsey, T.S., and Oltjen, R.R. 1975. Sulfur and choline in all-concentrate beef finishing diets. *Journal of Animal Science* 39: 1193.

Rumsey, T.S., Elsasser, T.H., Kahl, S., Moseley, W.M., and Solomon, M.B. 1996. Effects of Synovex-S and recombinant bovine growth hormone (Somavubove) on growth responses of steers: I. performance and composition of gain. *Journal of Animal Science* 74: 2917–2928.

Sawyer, W.A., Bogart, R., and Oloufa, M.M. 1948. Weaning weight of calves as related to age of dam, sex and color. *Journal of Animal Science* 7: 514.

Sime, C.A., Asher, V., Bradley, L., Lance, N., Laudon, K., Ross, M., et al. 2011. *Montana gray wolf conservation and management 2010 annual report.* Helena, Montana: Montana Fish, Wildlife and Parks.

Sime, C.A., Bangs, E., Bradley, E., Steuber, J.E., Glazier, K., Hoover, P.J., Asher, V., Laudon, K., Ross, M. and Trapp, J. 2007. Gray wolves and livestock in Montana: a recent history of damage management. In Proceedings of the 12th Wildlife Damage Management Conference, eds. Nolte, D.L., W.M. Arjo, and D.H. Stalman. 16–35.

Skonhoft, A. 2006. The costs and benefits of animal predation: an analysis of scandinavian wolf re–colonization. *Ecological Economics* 58 (4): 830–841.

Skrypzeck, H., Schoeman, S.J., Jordaan, G.F., and Neser, F.W. 2000. Pre-weaning growth traits of Hereford breed in a multibreed composite beef cattle population. *South African Journal of Animal Science* 30 (3): 220–229.

Sommers, A.P., Price, C.C., Urbigkit, C.D., and Peterson, E.M. 2010. Quantifying economic impacts of large-carnivore depredation on bovine calves. *Journal of Wildlife Management*, 74 (7): 1425–1434.

Stahl, P., Vandel, J.M., Herrenschmidt, V., and Migot, P. 2001. Predation on livestock by an expanding reintroduced lynx population: long-term trend and spatial variability. *Journal of Applied Ecology* 38: 674–687.

Steele, J.R., Rashford, B.S., Foulke, T.K., TAnaka, J.A., and Taylor, D.T. 2013. Wolf (*Canis lupus*) predation impacts on livestock production: direct effects, indirect effects, and implications for compensation ratios. *Rangeland Ecology & Management* 66: 539–544.

Stuth, J.W. 1991. Foraging behavior. In *Grazing Management: An Ecological Perspective*, ed. R.K. Heitschmidt and J.W. Stuth, 65–83. Portland, Oregon: Timber Press.

Swiger, L.A., Koch, R.M., Gegory, K.E., Arthaud, V.H., Rowden, W.W., and Ingalls, J.E. 1962. Evaluating pre-weaning growth of beef calves. *Journal of Animal Science* 21: 781–786.

Tawonezvi, H.P. 1989. Growth of Mashona cattle on range in Zimbabwe. 1. Environmental influences on liveweight and weight gain. *Tropical Animal Health Production* 21: 37–42.

Tawonezvi, H. ., Brownlee, J.W., and Ward, H.K. 1986. Studies on growth of Nkone cattle. 1. Environmental influences on body mass. *Zimbabwe Journal of Agriculture Research* 24: 17–29.

Thoma, D.P., Bailey, D.W., Long, D.S., Nielsen, G.A., Henry, M.P., Breneman, M.C. and Montagne, C. 2002. Short-term monitoring of rangeland forage conditions with AVHRR imagery. *Journal of Range Management* 55: 383–389.

Thorpe, W., Cruickshank, D.K., and Thompson, R. 1980. Genetic and environmental influences on beef cattle production in Zambia 1. Factors affecting weaner production from Angoni, Barotse and Boran dams. *Animal Production* 30: 217–234.

Torstenson, W.L., Tess, M.W., and Knight, J.E. 2002. Elk management strategies and profitability of beef cattle ranches. *Journal of Range Management* 55 (2), 117–126.

Treves, A., Jureviez, R.R., Naughton-Treves, L., Rose, R.A., Willging, R.C., and Wydeven, A.P. 2002. Wolf depredation on domestic animals in Wisconsin, 1976-2000. *Wildlife Society Bulletin* 30 (1): 231–241.

Treves, A. and Karanth, K.U., 2003. Human-carnivore conflict and perspectives on carnivore management worldwide. *Conservation Biology* 17 (6): 1491–1499.

U.S. Department of Agriculture, National Agricultural Statistics Service. 2010. *Agricultural Prices.*

U.S. Fish and Wildlife Service. 1987. *Northern rocky mountain wolf recovery plan.* Denver, Colorado.

Van Soest, P.J., ed. 1982. Nutritional ecology of the ruminant. Corvallis, Oregon: O and B Books.

White, P.J., Garrott, R.A., Hamlin, K.L., Cook, R.C., Cook, J.G., and Cunningham, J. 2011. Body condition and pregnancy in northern Yellowstone elk: evidence for predation risk effects? *Ecological Applications* 21: 3–8.

Wiltbank, J.N., Gregory, K.E., Swiger, L.A., Ingalls, J.E., Rothlisberger, J.A., and Koch, R.M. 1966. Effects of heterosis on age and weight at puberty in beef heifers. *Journal of Animal Science* 25: 744–751.

Woodroffe, R., S. Thirgood, and Rabinowitz, A. editors. 2005. People and wildlife, conflict or coexistence? Cambridge, UK: Cambridge University Press.

Wooldridge, J.M. 2002. Econometric Analysis of Cross Section and Panel Data. Cambridge, MA: MIT Press.

Young, S.P., and Goldman, E.A. 1944. *The Wolves of North America.* Washington DC: The American Wildlife Institute.

Zalesky, D.D., B.A. LaShell, and Selzer, D.R. 2007. *Comparison of pre-weaning growth traits for early and late spring claving.* Colorado State University.