Crying Wolf?
A Spatial Analysis of Wolf Location and Depredations on Calf Weight

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Abstract: 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 a large degree of 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. The costs of these indirect weight losses are shown to potentially be greater than the costs of direct depredation losses which have, in the past, been the only form of compensation for ranchers who have suffered wolf depredations.

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I. INTRODUCTION

The 1995 reintroduction of the gray wolf to Yellowstone National Park and northern Idaho rekindled a decade's long debate on the social benefits and costs of wolves on the natural landscape. Proponents argue 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 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 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 do not seek to answer the question of whether the net social costs of wolves is positive or negative, but instead focus on one intriguing and understudied component of changing wolf locations: the effects of wolf location and wolf depredations on the weight of domestic calves.

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 & Pletscher, 2005; Bradley, et al., 2005; Breck & Meier, 2004; Oakleaf, Mack & Murray, 2003; Treves, et al., 2002; Stahl, et al., 2001). However, it has been suggested that predators may have impacts on livestock reaching beyond direct depredation (Kluever, et al., 2008; Howery & DeLiberto, 2004). One claim in particular is that wolves decrease the average weight of calves (Alderman, 2006) by stressing mother cattle, increasing movement rates, or encouraging inefficient foraging behavior. To date, no studies have empirically estimated the indirect effects of wolves 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, suggesting that simply having wolf home ranges that overlap with cattle grazing areas has no effect on cattle behavior that would affect calf weights. 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 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 ranches 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. We show that there are negative impacts on calf weights across the herd beyond the direct loss of depredation.

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. In Section III, we present the empirical model and the data used in the analysis as well as the relationship between the model and the relevant literature. In Sections IV and V we present the results of the analysis as well as a discussion of the economic impacts of the results and in Section VI we conclude.

II. BACKGROUND

Gray wolves roamed freely and extensively throughout the mountains and grasslands of what is present day Montana during the time of the Lewis & Clark Expedition from 1804 to1806 (Young & Goldman, 1944). However, it wasn't long after that cattleman began driving herds of cattle up from Texas in search of pastureland for their stock (Power & Barrett, 2001, p. 51) 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 lead 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 & Maurer, 2004; Mech, 1970).

This remained true until the late 1970's, 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 & Blakesley, 1989). Since then, the resident wolf population in northwestern Montana has increased naturally (Boyd et al., 1995; Ream, Fairchild, Boyd & Blakesley, 1989).

In an effort to fully restore the gray wolf under the federal Endangered Species Act, Congress directed the United States Fish & Wildlife Service (USFWS) to facilitate recovery by actively reintroducing the gray wolf into other suitable areas of the US Northern Rockies such as Yellowstone National Park (YNP) and central Idaho (USFWS, 1987). After reintroduction, wolf number and distribution steadily expanded beyond YNP, encompassing both public and private lands. As a consequence, rural ranchers have seen an increase in wolf inhabitance on and around their lands. As of December 31, 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 United States Department of Agriculture: Wildlife Service (WS) confirmed that 87 cattle were killed by wolves statewide. However, 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 wolves have on cattle ranchers. Although domestic cattle aren't natural prey for wolves, they have become a food target of wolf packs in the US due to their abundance and vulnerability (Harper, Paul & Mech, 2005). The potential for depredation of livestock was recognized by state and federal agencies before wolves were reintroduced into YNP and central Idaho (Sime et al., 2011; USFWS, 1987). These depredations have resulted in monetary losses to individual ranchers which 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. After investigating a case of suspected predation the WS agent will issue a report including their expert opinions on the incident. One of three possible conclusions will be submitted in the report: it is "confirmed[1]"

[1] 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).

that predators were the cause of the death or injury; it is "probable[2]" 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 get monetary compensation for their loss, the investigating agent must conclude that their loss was either a "confirmed" or "probable" wolf depredation incident. The available avenues of compensation for Montana ranchers affected by wolf predation have changed over time.

The first available compensation for Montana ranchers affected by wolf depredations came 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). 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, DOW capped compensation at $3,000 per lost animal (Frequently Asked Questions about the Wolf Compensation Trust, 2011).

From 1987 through 2009, 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 experience wolf predation (Wolf Compensation

[2] 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).

Payment Statistics, n.d.). With Montana's program underway following delisting of wolves in 2009, DOW ceased directly compensating ranchers as of September 2010.

In 2007 the Montana Legislature created the Montana Livestock Loss Reduction & Mitigation Board (LLRMB). The LLRMB 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[3].

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 (Agriculture & Business, 2007). While calves are still nursing, the cow-calf pairs are let out to pasture land for the summer and early Fall to graze. Montana summer pasture for cattle is privately deeded or public land leased to a ranch by the United States 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[4] (Hanawalt, 2011). Livestock producers typically have a target in mind for what their calves should weigh at the time of weaning. 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.

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

[4] A feeder calf is a weaned calf sold to a feedlot where it will be fattened up for the purpose of beef production.

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

III. 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 combines 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. The dataset contained ranches that have been impacted by wolf presence and those that have not, which allowed us to estimate the average treatment effect of known wolf activity on calf weight using a quasi-experimental panel level differences-in-differences approach. Prior research has used linear regression procedures to estimate the effects of calf sex (Barlow, Dettmann & Williams, 1978), genetic and environmental factors (Brown, Brown & Butts, 1972), and other covariates (Cundiff, Willham & Pratt, 1966 and Dal Zotto, et al., 2009) on calf weight. The empirical model used in the analysis builds on this prior calf weight 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 a treatment effect for the time-variant spatial location of known wolf-pack home ranges and confirmed kills of cattle by wolves. There are two observations, an average heifer (female calf) weight and average steer (male calf) weight, for each ranch i in year t. The regression model is displayed in equation (1) below:

$$calf\_weight_{it} = \sum_{i=1}^{18} \alpha_i + \sum_{t=1}^{16} \alpha_t + \mathbf{x_{it}} \boldsymbol{\beta} + \mathbf{w_{it}} \boldsymbol{\eta} + e_{it} \quad . \tag{1}$$

The coefficients, α_i and α_t, are ranch and year specific fixed effects. 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 & Casey, 2000; Brown, Brown & Butts, 1972). Ranch fixed effects are included to capture all unobserved ranch specific characteristics (such as unobserved husbandry practices, ranch terrain characteristics such as slope and elevation, or ranch geography) 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 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. However, we contacted several livestock industry associations and organizations which maintain membership databases. 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 interested in these issues is able to join. However, sampling from these organizations' membership lists provided a more focused population to identify cow-calf producers in Montana. Working closely with several of these organizations[5], 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[6]. 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 able provide the necessary survey information. For those willing and able to provide the necessary information, 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 that could have a direct influence on the weaning weight of the calves[7]. Of the 826 letters and emails sent out, 54 (6.54%) responded. Many respondents did not qualify for participation (e.g. did not raise feeder calves, had not been ranching for a long enough period of time, did not have sufficient records of past calf weight, etc.) and therefore were not selected for on-ranch interviews. Of the 54 respondents, 21 were selected for an on-ranch interview; 18 of which were used in this study[8].

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[5] 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.

[6] 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.

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

[8] 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 so these 2 ranches were not included in the analysis. A third ranch ultimately ended up having 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 if 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[9], 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 & Selzer, 2007; Barlow, et al., 1978; Swiger, et al., 1962). Previous

[9] Data was downloaded from ftp://ftp.gis.mt.gov/cadastralframework. The Cadastral Database is being continually updated to account for changing land ownership status. The data used in this study are current through October 10, 2010. See the Appendix: Figure 8 for a breakdown of when the county specific data used in this study were last updated.

lactation status[10] of mother cows has been shown to influence the average daily weight gain and weaning weight of calves (Beffa, van Wyk & Erasmus, 2009). Younger mother cows demand extra forage consumption for their own physical growth, which decreases milk production necessary for optimal calf growth (Hetzel, et al., 1989; Tawonezvi, 1989; Tawonezvi, Brownlee & Ward, 1986; Thorpe, Cruickshank & Thompson, 1980).

The effect of age of the mother cow on weaning weight of calves has been intensely researched, but findings vary 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, & Erasmus, 2009) in one study and 6-9 year old dams (Minyard & Dinkel, 1965) in another. Other researchers found the maximum production age of a cow to be between 6-10 years (Sawyer, Bogart & Oloufa, 1948; Rollins & Guilbert, 1954; Burgess, Landblom & Stonaker, 1954; Nelms & Bogart, 1956; McCormick, Southwell & 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 the cow had reached full maturity.

The yearly replacement of old 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

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

mother cows on a ranch stayed constant over time, the effect of the mother cow's age on calf weaning weights was captured 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 & 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 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 changed their supplemental feeding regimens over the time period of the study and thus, the variation in supplemental feeding practices 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 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)[11] have been shown to wean as much as 7% heavier than heifer calves (Beffa, van Wyk & Erasmus, 2009). Other researchers have found 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[12].

CALF AGE

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

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, centered on the middle of the calving season (Minyard & Dinkel,

[11] Steers are male calves that have been castrated. A male calf that has not been castrated is referred to as a bull calf.
[12] . There are slightly fewer heifer observations as there were a few ranches that only recorded their steer weights for some years.

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 & Butts, 1972), although Minyard & 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 & 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 & Cartwright, 1986). This study incorporates 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 calves are observed in this study with the most prevalent being Black Angus.

HORMONE IMPLANTING

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., 1954). Average daily weight gain of finishing steers[13] has been shown to increase by 16% (Rumsey, et al., 1996) and as much as 23% (Kahl, Bitman & Rumsey, 1978) when implanted with a growth

[13] 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.

hormone (Synovex-S[14]) compared to steers with no growth hormones of similar physical character and raising conditions (Dimius, et al., 1976; Embry & Gates, 1976; Rumsey & Oltjen, 1975). Not only do growth hormones stimulate increased weight gain but some types do so while increasing the feed conversion efficiency (FCE) or decreasing the necessary amount of forage needed to sustain optimal growth trends in steers (Animal & 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 & Van Keuren, 1962). Over our sample period, the use of hormone implanting was decreasing over time. To control for heterogeneous use of hormone implanting on ranches in different years we include a dummy variable indicating whether ranch *i* used hormone implanting in year *t*.

STOCKING DENSITY

Livestock husbandry practices such as stocking 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 as well (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 others theorized that overuse of some foraging areas by both wild and domestic ungulates results from avoidance of other areas that may have an increased risk of predation (Kotler & Holt, 1989). Cattle group size and its effect on foraging efficiency and rate of vigilance has been a heavily debated topic with no clear

[14] Synovex is an implant containing estradiol and progesterone used to boost weight gain of calves during the growing and finishing process of cattle production

conclusion (Elgar, 1989). Various authors found a negative correlation between group size and rate of vigilance (group-size effect) in white-tailed deer (Lagory, 1986), springbok in Botswana (Bednekoff & Ritter, 1994), and impalas and wildebeests in South Africa (Hunter & Skinner, 1998). However, others looking at elk and bison in Yellowstone National Park (Laundre, Hernandez & Altendorf, 2001) and various species of birds (Lima, 1995) did not find any significant group-size effect 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 effect of stocking density or group size on calf weight.

RANGE RIDERS AND ARTIFICIAL INSEMINATION

Two other variables that did change over time for a few ranches was the use of range riders and the use of artificial insemination of heifers. If a ranch implemented the use of range riders, people were hired to be in and around the cattle (generally on horseback) almost every day while the cattle were grazing on summer pasture. Although the majority of our sample did not use artificial insemination or hire range riders, these time-variant variables are potentially important ranch specific husbandry practices that would not be captured by the ranch specific fixed effect and therefore are included in the estimation model.

ENVIRONMENTAL FACTORS

CLIMATE VARIABLES

Differences in environmental rearing conditions of beef calves can affect calf weights. 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 & Butts, 1972; Azzam et al., 1993; Beffa, van Wyk & Erasmus, 2009). For example, Kamal and Johnson [1971] find that Friesian[15] calves exposed to three consecutive days of high ambient heat can lose 15% of their body weight, while Kamal & Seif [1969] found a 27% decline in total body weight of adult Friesian cows when exposed to increased heat. In yet 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 potential impacts of climatic changes on calf weight from year to year, average annual temperature and aggregate snowfall and precipitation measures are included in $\mathbf{x}_{\mathbf{it}}$.

Raw data on monthly average temperature and aggregate rainfall and snowfall was obtained from the Western Regional Climate Center's (WRCC) website[16]. Data comes from 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.

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 & DeLiberto, 2004), which has been represented as a product

[15] Friesian cows are a breed of cattle most commonly raised for dairy production. Though there are some red and white colored Friesian cattle, the majority Friesians depict the iconic image of an American dairy cow with a black and white hide (Cattle breeds: Friesian, n.d.).
[16] Data was downloaded from the Western Regional Climate Center's website working with the National Weather Service (NWS) Cooperative Observer Program (COOP). url: http://www.wrcc.dri.edu/coopmap/ .

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 energy to be gained from the least amount of energy expended while feeding (MacArthur & 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 & 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, concluding that wild ungulate such as elk (Hebblewhite, Merrill & 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 used in the estimation model.

The Normalized Difference Vegetation Index (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) polar-orbiting 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 which range from values of -1 to +1.[17] A larger calculated NDVI value represents "greener" vegetation on the ground. Generally, any NDVI value less than zero is representative of snow, rock, sand, or anything non-vegetative covering the land (Remote Sensing Phenology: NDVI the foundation for Remote Sensing Phenology, 2011). Following other researchers (PLM - Patuxent Landscape Model), the NDVI data used in the analysis was re-scaled from 0 to 200.

NDVI is used in this study as a measure of forage available each year to the cow-calf pairs on each sample ranch. The NDVI data can be thought of as a curve connecting the 6-day composite scaled NDVI values representing the relative "greenness" of vegetation on ranch *i* in year *t*. In order to create a consistent time interval for measurement across years, the NDVI measures are calculated from approximately February 1st to November 30th 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). Looking at Figure 1, total NDVI of "Curve A" is greater than that of "Curve B." To get 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 get mean NDVI. Because mean NDVI is a factor of total NDVI, "Curve A" also has a larger mean NDVI value than that of "Curve B". To measure the rate of "green-up," 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). In Figure 1, "Curve A" has a larger standard deviation than that of "Curve B" implying that "Curve A" represents a longer vegetative growing season compared to that of "Curve B." Because the dependent variable is a measure of yearly

[17] The AVHRR data used in this study is in 6-day composites.

average calf weight, yearly average NDVI mean and standard deviation measures are used in the estimation model to control for changes in forage availability and quality across sample ranches and 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 & DeLiberto, 2004), and various studies have substantiated this behavior in a variety of prey species (Kotler et al., 1991, Brown & Morgan, 1995, and Kotler et al., 1994). However, predator presence may also affect prey species behavior by increasing time allotted to habitat selection (Kotler & 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 & 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).

Addition of a predator to a habitat that was previously a safe-haven for prey will change the potential energetic gains of that prey because of a number of potential mechanisms. Hunter & Skinner [1998] find that after the reintroduction of lions and cheetahs, impalas and wildebeest increased the 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 & Altendorf, 2001). When mother elk perceive a threat from predators they spend more time 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 (Muhly et al., 2010). 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, and increased movement rates in response to heightened predation risk may also increase energetic costs, 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 & Knight, 2002; Alt, Frisina & King, 1992; Holechek, 1980). The presence of predators in a given area may induce competing foraging species (i.e. cattle, elk & deer) to choose the same areas to feed, thus diminishing the available forage faster than if predators were not around (Kotler & Holt, 1989).

Given the variety of ways that changes in predator presence may impact forage efficiency and stress, this paper 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 in this study is constructed using wolf population and spatial distribution data collected through routine monitoring by USFWS from 1995 – 2004, and Montana Fish, Wildlife & Parks (MFWP) from 2005 – 2010. Data for both periods were provided by MFWP.

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 is gathered using direct observational counts through radio telemetry, howling and track surveys, and public wolf reports (Sime, Asher, Bradley, 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 outer most observation points (Kie, Baldwin & Evans, 1996; Mohr, 1947). MFWP creates yearly wolf home range MCPs by compiling documented wolf locations (using mostly 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, Asher, Bradley, 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 times 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 to be 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 do not appear to be substantially different with respect to observables, the simple difference-in-means are 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). The most pronounced and notable difference in the two groups is in the average number of calves, with treatment ranches having approximately twice as many calves on a ranch as control group ranches. These differences in means suggest that the control and treatment groups have important statistical differences that we must account for in estimation. Of course, if wolf activities on a ranch in a particular year, $\boldsymbol{w}_{it}$, are truly random exogenous effects that are uncorrelated with e_{it}, the $\boldsymbol{\eta}$ coefficients will 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 will simply improve the efficiency of the estimates.

IV. RESULTS

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 is counter-intuitive, but explained in subsequent regressions by inclusion of more 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 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 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 ranches that did not experience a confirmed wolf depredation.

The regression in column (3) makes 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 is not a problem for consistent estimation of our wolf variables as these factors are controlled for by the ranch fixed effects. If however, the time-variant factors are 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, hormone implanting, and annual precipitation are all positive and statistically significant determinants of calf weight, while annual aggregate snowfall has a statistically significant negative impact on calf weight. The estimates on wolf home range and wolf depredations remain 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) explains 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 are likely to be correlated and could lead to an overestimation of the *t*-statistics (Bertrand, Duflo & Mullainathan 2004), so the errors were clustered on the ranch-year observation. Although the standard errors increased slightly, the statistical significance of the results is 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). The results of the beta coefficients are instructive, because 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 effects are relatively small when compared to other factors that affect calf weight. This is particularly true when the wolf depredation coefficient is compared to standard deviation changes in climatological factors such as precipitation or snowfall, or to observable husbandry practices like the age of the calves at weaning and hormone implanting.

While we must be careful about interpretations of the beta coefficients on dummy variables such as the WS wolf depredation variable, the coefficients are instructive in understanding the relative importance of wolf depredations when compared to other factors influencing calf weight in Montana.

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 Wildlife Services 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 1km and 5km to test for more liberal interpretations of wolf pack home ranges. This however, did not change the results when using the original MCP and centroid data. Ranches with wolf-pack home-ranges overlapping their grazing allotments still have no statistically significant effects on calf-weights[18].

In column (5) of Table 3, we estimated the effects of a placebo variable to test the robustness of the Wildlife Services 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

[18] In addition to buffering the wolf pack home ranges by 1km and 5km, 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 MCP's 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.

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.

V. DISCUSSION

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 simply the cost of the injury or death loss. In our sample, the average ranch had 264 calves with a weaning (sale) weight of 626 pounds[19]. In November of 2010, the average selling price of steers and heifers in Montana was $1.15 per pound (USDA, 2010). 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 statistically significant effect is not large, neither is it negligible. 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.

[19] The average annual herd size across the 18 sample ranches was 264 calves at an average combined heifer and steer calf weight of 626 pounds.

In 2011, 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 make the assumption 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 would be a loss of $247,130.

To put these estimates into context, consider that in 2011, the Montana Livestock Loss Reduction & Mitigation Board (LLRMG) paid $75,389 to Montana ranchers for 83 cattle that were confirmed or probable wolf predations[20]. 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 indirect economic losses through lower calf weaning weights from wolf depredation are potentially substantial when compared to those from direct 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 actual number of ranches that are affected by at least one WS confirmed wolf depredation.

Further, our results also emphasize that the amount of variation in calf weight due to wolf effects is relatively small when compared to other factors such as ranch specific effects and changes in climatological factors. 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 ranch's in our sample. In contrast, it was evident when ranch fixed effects are included in column (3) of Table 2 that 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

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

covariates (including ranch and year-specific effects) were included in column (5). 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 & Erasmus, 2009 and Hanawalt, 2011) in weight between steer and heifer calves. Finally, calf age influenced weight gain by an average of 0.34 pounds/day, a bit smaller in magnitude, but still similar to previous studies estimates of 1.2 to 1.47 pounds per day (Botkin & Whatley, 1953, Koger & Knox, 1945, and Minyard & 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.

VI. 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 that may be designed to compensate for losses generated by wolves require the best available science and information to make effective policy decisions. In this paper we focus on one important component of wolf interactions 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 panel data on 18 ranches in western Montana and combining it with spatial data on wolf locations and satellite generated climatological data, we found that ranches with wolf home ranges that overlap ranch pasturing areas has 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, individual calf-weights fall by 3.5%, or 22 pounds, relative to ranches that did not experience a confirmed wolf depredation that year. For the average ranch in our sample, this translates into a $6,679 loss across the herd at the time of calf sale.

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. However, which strategies 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 cannot answer those more detailed biological questions but should be a fruitful and important area of future research.

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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

+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 x 16 x 2=576 potential panel of observations).

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

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	

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%

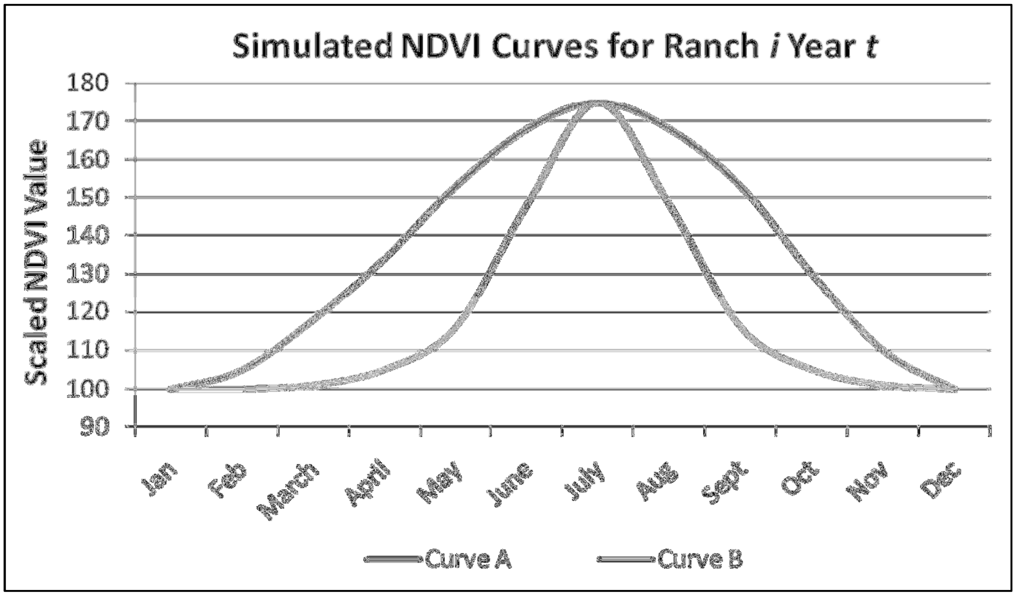
Table 3: Robustness Tests					
	(1)	(2)	(3)	(4)	(5)
Ranch Overlaps MFWP Wolf Home Range					
– all original MCPs and centroids		2.85			2.793
		(4.149)			(4.146)
– all MCPs and centroids buffered by 1 km			2.912		
			(4.146)		
– all MCPs and centroids buffered by 5 km				6.216	
				(3.987)	
Wildlife Service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

[1] Original confirmed wolf depredation variable used in columns (1) - (4); Plasebo variable used in column (5)

Columns (1)-(5) report clustered errors, clustered on the ranch-year observation.

* significant at 10%; ** significant at 5%; *** significant at 1%

Figure 1



Simulated NDVI Curves for Ranch *i* Year *t*
Scaled NDVI Value
180
170
160
150
140
130
120
110
100
90
Jan
Feb
March
April
May
June
July
Aug
Sept
Oct
Nov
Dec
Curve A
Curve B