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The Economic Impacts of Wolves on Calf Production on Western Montana Cattle Ranches Beyond Direct Depredation

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THE ECONOMIC IMPACTS OF WOLVES ON CALF PRODUCTION

ON WESTERN MONTANA CATTLE RANCHES

BEYOND DIRECT DEPREDATION

By

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The economic impacts of wolves on calf production on western Montana cattle ranches beyond direct depredation

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A novel sample of 18 western Montana cow-calf ranching operations were analyzed over a 16 year time period (1995-2010) using an ordinary least squares linear regression estimation model with robust standard errors focused on the potential effects wolves may have on average calf weight gain. Incorporating calf sex, calf breed, ranch, and year fixed effects into the estimation model, a vector of variables that changed both across ranches and over time were used to significantly explain ($F = 59.32$; $p < 0.001$) the variation in yearly average calf weaning weights on sample ranches with fairly good accuracy ($R^2 = 0.846$). The use of hormone implanting (β=24.5), calf age (β=.34), annual aggregate precipitation (β=2.16), annual aggregate snowfall (β=-0.24), annual average temperature (β=4.27), and the standard deviation of NDVI (β=1.67) were found to be significant at least at the .1 level. One measure used to account for wolf presence on sample ranches based on yearly estimated wolf home range data from Montana Fish, Wildlife & Parks was found to have an insignificant effect on average calf weight ($p = .569$). The other measure used to account for wolf presence on sample ranches was found to be a significant factor on calf weight gain. On average, sample ranches that experienced at least one Wildlife Service (WS) confirmed wolf depredation on the ranch, weaned calves that were approximately 20 pounds lighter than ranches that did not have a WS confirmed wolf depredation in the same year, holding all else constant. The results suggest that calves on western Montana ranches that experience at least one WS wolf depredation in a year gain 20 pounds less weight than if there hadn't been a WS confirmed wolf kill which directly correlates to decreased economic revenue received by affected ranchers.

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Introduction

Historically, studies concerned with the impact of predators on domestic livestock have been conducted assessing direct depredation rates (Sommers, et al., 2010; Bradley & Pletscher, 2005; Bradley, et al., 2005; Breck & Meier, 2004; Oakleaf, Mack & Murray, 2003; Treves, et al., 2002; Stahl, et al., 2001) however, some researchers have suggested that predators may have an impact on livestock reaching beyond direct depredation (Kluever, et al., 2008; Howery & DeLiberto, 2004). The reintroduction of the gray wolf into Yellowstone National Park and central Idaho has directly impacted cattle ranching in Montana through depredation on herds (Muhly & Musiani, 2009; Mech, 1996), but allegations have also been made suggesting that increased presence of wolves around cattle herds may be negatively affecting ranchers' pocketbooks by decreasing the average weight gained by their calves (Alderman, 2006). This study empirically analyzes a sample of yearly average calf weaning weights from western Montana cattle ranches, most known to have documented wolf packs in the area, considering an array of variables other than wolf presence such as animal husbandry and weather that may also influence calf weight gain.

Prior to the Lewis & Clark Expedition (1804-1806), gray wolves roamed freely and extensively throughout the mountains and grasslands of what is present day Montana (Young & Goldman, 1944). Shortly after the West was "discovered," cattleman started pushing herds up from Texas on great cattle drives in search of pastureland for their stock (Power & Barrett, 2001, p. 51). After bison, elk, deer, and other natural prey species of wolves were hunted to near extinction by western settlers, wolves and other predatory species posed an increasing depredation threat to the growing livestock industry and were subsequently targeted for eradication (United States Fish & Wildlife Service, 1994). 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, Nessiage & Maurer, 2004; Mech, 1970).

Wolves from Canada began to move south and naturally recolonize Glacier National Park (GNP) in northern Montana in the late 1970s (Ream, Fairchild, Boyd & Blakesley, 1989). 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, wolves have continued to naturally grow into a small resident population in the Northwestern Montana (Boyd, Paquet, Donelon, et al., 1995; Ream, Fairchild, Boyd, Pletscher, 1991).

In an effort to restore the gray wolf under the federal Endangered Species Act, Congress directed the United States Fish & Wildlife Service (USFWS) to facilitate recovery through actively reintroducing the gray wolf into suitable areas of the US Northern Rockies such as Yellowstone National Park (YNP) and central Idaho (United States Fish & Wildlife Service, 1987). The first wolves were reintroduced into YNP (14 wolves) and central Idaho (15 wolves) after being darted and moved in January 1995 using helicopters around Jasper National Park in Alberta (Bangs & Fritts, 1996). The following January, 17 wolves were released into YNP and 20 in central Idaho after being captured north of Fort St. John, British Columbia (Bangs & Fritts, 1996). As of December 31, 2010 the Montana wolf population has grown to an estimated minimum number of 566 wolves (Sime, Asher, Bradley, et al., 2011).

In Montana, the average wolf pack is estimated to occupy a 200 square-mile territory with some pack territories reaching 300 square miles or greater (Sime, Asher, Bradley, et al., 2011). After reintroduction, wolf number and distribution steadily expanded beyond YNP, encompassing both public and private lands (Sime, Asher, Bradley, et al., 2011). As a consequence, rural ranchers have seen an increase in wolf inhabitance on and around their lands.

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 detrimentally affected by wolves statewide; although, most of Montana's wolves routinely encounter domestic livestock but do not kill any livestock (Sime, Bangs, Bradley, 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 the cattle ranching industry. Although domestic cattle aren't natural prey for wolves, they have increasingly become a food target of wolf packs in the Midwestern part of the US due to their abundance and vulnerability (Harper, Paul & Mech, 2005). The potential for negative interactions between wolves and humans such as depredation of livestock was recognized by state and federal agencies before wolves were reintroduced into YNP and central Idaho (Sime, Asher, Bradley, et al., 2011; United States Fish & Wildlife Service, 1987). The realization of the negative interactions between some wolves and livestock has resulted in monetary losses to individual ranchers which can be addressed, at least partially, through economic compensation for lost livestock.

For Montana ranchers to receive monetary compensation for suspected losses due to wolves, the killed or injured animal must be investigated by a United States Department of

Agriculture: Wildlife Service (WS) agent (Montana Livestock Loss Reduction & Mitigation Board, n.d.). 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]" 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 personnel also determine 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" predator 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 group—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). For ranchers to

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[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 Legislature, 2009).

[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 Legislature, 2009).

receive reimbursement from the trust a WS investigation report was sent to the DOW who estimated the value of the lost livestock based on rancher's assessment of value and local auction prices and reports. The Defenders 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 animal in question may be assessed at a higher value, the Defenders capped their compensation to ranchers 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 issued to the state to help fund a state-run compensation fund for ranchers who experience wolf predation (Wolf Compensation Payment Statistics, n.d.). With the state taking over the reins on rancher compensation, as of September of 2010, the DOW no longer offer monetary support directly to livestock producers who are affected by wolf predation in Montana (Frequently Asked Questions about the Wolf Compensation Trust, 2011).

In 2007 the Montana Legislature created the Montana Livestock Loss Reduction & Mitigation Board (LLRMB) (Livestock loss reduction and mitigation board -- purpose, membership, and qualifications, 2007). Beginning in April of 2008, the LLRMB currently acts as the sole means of reimbursement to Montana livestock producers for "confirmed" and "probable" livestock losses due to wolf depredation (Montana Livestock Loss Reduction & Mitigation Board, n.d.).

Like the DOW, the LLRMB stipulates that all wolf depredation investigations must be conducted by the United States Department of Agriculture Wildlife Services (Montana Livestock

Loss Reduction & Mitigation Board, n.d.). After the WS investigator sends their report to the USDA Wildlife Service's state director, a copy of the report and a LLRMB claim form is sent to the affected livestock producer which can be submitted to the LLRMB office by the rancher.

Upon receiving the claim, the Livestock Loss Mitigation Coordinator determines a monetary value to the lost animal(s) based on the current USDA Market Report from Billings, Montana. If the lost livestock are contracted[3] at a higher price than currently valued by the market report a copy of the contract must be produced by the rancher to verify such valuation. After an agreed value of the lost livestock is determined, a letter confirming the payment for the loss is sent to the producer and the Department of Livestock's accounting department who subsequently issues a check for compensation. If the producer disagrees with the appraisal of the animal(s) in question, a letter must be submitted to the LLRMB providing evidence in favor of increasing the livestock value which is then reviewed by the Board (Montana Livestock Loss Reduction & Mitigation Board, n.d.). Through 2009 the LLRMB has issued just over $232,000 in compensation to ranchers for losses due to wolf predation in Montana since its first payment in April of 2008 (Sime, Asher, Bradley, et al., 2011). Though claims are still being submitted to the Board for wolf predation incidents in 2010, the LLRMB has paid ranchers over $98,000 in economic compensation for the year (Edwards, 2010).

MONTANA CATTLE RANCHING

Cattle ranches in Montana are predominately cow-calf operations. Mature female cows (cows) are bred to bulls (sires) 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

[3] Instead of selling calves at the current market value when the calves are weaned it is common for producers to contract their calves to a buyer at an agreed-upon set price before the livestock have reached sale maturity. This future price could potentially be greater than the current market value for the livestock in question.

cow-calf pairs (pairs) are let out to pasture land for the summer and early fall to graze (summer pasture). Montana summer pasture for cattle is privately deeded or public land leased to a ranch by the United States Department of the Interior: Bureau of Land Management (BLM) (Bureau of Land Management, 2010) or the United States Forest Service which is referred to as a grazing allotment.

Calves stay with the mother cows for about 6 months until they are weaned off of the cows in the fall and then generally sold as feeder calves[4] (Hanawalt, 2011). Because many cow-calf producers breed, calve, and wean at similar times during the year, the market for feeder calves becomes flooded during the fall months subsequently driving the market price of calves down. Some ranchers opt to background[5] their calves for a few months betting that the market price for feeder calves will rise in the near future. Historically, agricultural areas had local auction barns where producers would take their calves to be sold. Though auction barns are still in use advances in communication technology has given producers more options such as internet and video auctions to sell their stock in larger feeder calf markets (Zehnder & DiCostanzo, n.d.). Circumventing the auction process completely, producers may choose to find a private party (generally a feedlot operator or a contracted agent for a feedlot) who agrees to pay a set price per pound for the calf crop when they are ready for sale (Zehnder & DiCostanzo, n.d.). Regardless of the route ranchers decides to take in selling their calves, generally, all feeder calves are sold on a price per pound basis.

[4] A feeder calf is a weaned calf sold to a feedlot where it will be fattened up for the purpose of beef production.
[5] Instead of selling the calves directly after they are weaned off of the cows in the fall, a rancher may decide to hold onto and feed the calves solid forage, such as hay, and sell them at a later date. This is known as backgrounding the calves before selling.

Producers typically have a target in mind for what their calves should weigh at the time of weaning. They budget their time, finances, and other resources accordingly throughout the year expecting to get a certain dollar amount at the time of sale. If a herd of calves that, on average, weigh less than expected when sold directly affects a producer's profit margin; therefore, it is paramount 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 range beef calf weight gain (CWG) in western Montana, it is imperative to understand what else may also affect pre-weaning CWG trends. Below is a review of the literature about animal husbandry and environmental factors influencing CWG, predator/prey interactions, and the potential link between the two.

Literature Review

Ranch Specific Husbandry Practices

Differences in ranch specific husbandry practices can affect trends in CWG. Cow-calf operations breed their mother cows, calve, and wean at different times during the year. Different cow-calf producers have inherently different herds of cattle and idiosyncratic styles of husbandry practices which can lead to differences in calf birth weight which ultimately influences the calves' weights at weaning across ranching operations (MacGregor & Casey, 2000; Brown, Brown & Butts, 1972).

Sex of Calf

The sex of the calf has consistently been shown to have an effect on CWG and weaning weight (Barlow, Dettmann & Williams, 1978). Barlow et al. (1978) found that male Angus calves wean on average 16.58 kg heavier than their female counterparts. Castrated male calves (steers)[6] have been shown to wean, on average, as much as 7% heavier than heifer calves (Beffa, van Wyk & Erasmus, 2009). Other researchers have found steers gain, on average, approximately 5% more weight than their female counterparts of the same age and breed (Hanawalt, 2011).

Calf Age

With calving seasons sometimes spanning 100 days or more, a direct relationship between the birth date of an individual calf and its weight at weaning has been shown to be significant within a herd of certain breeds of cattle (Beffa, van Wyk & Erasmus, 2009). Researchers have shown through linear regression of age (in days) on weaning weight (pounds)

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

of a calf is 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 effects of age of a calf on weaning weight with a magnitude of 1.33 pounds (Koger & Knox, 1945) and 1.20 pounds (Minyard & Dinkel, 1965) per day.

AGE OF MOTHER COW

The average age of the herd has been shown to affect the weight gained by pre-weaned calves as (Zalesky, LaShell & Selzer, 2007; Barlow, et al., 1978; Swiger, et al., 1962). Previous lactation status[7] of mother cows has been shown to influence the average daily gain and weaning weight of calves (Beffa, van Wyk & Erasmus, 2009). Because a younger cow demands extra forage consumption for her own physical growth, a suboptimal amount of energy will be allocated to milk production which is 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 there is considerable variation among findings across studies which may be due to differences in breeds, genetic selection, and experimental practices. Weaning weights of calves increase with the increase 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 have found the maximum production age of a cow to be 8 years (Sawyer, Bogart & Oloufa, 1948; Rollins & Guilbert, 1954), 6-10 years (Burgess, Landblom &

[7] 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.

Stonaker, 1954; Nelms & Bogart, 1956; McCormick, Southwell & Warwick, 1956), 6 years (Koch & Clark, 1955), and 7 years (Marlowe & Gaines, 1958).

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. These findings by Barlow et al. (1978) are consistent with the Beef Improvement Federation (2002) who advise weaning weight adjustment factors be used for calves born to 2-4 year old female cows.

The yearly replacement of old cows with younger cows with little or no previous mothering experience may have an impact on the average calf weaning weight of a herd. Though this study does not quantifiably account for the age of mother cows in the sample ranch herds, the yearly replacement rate of old cows with new, younger cows within a sample ranch herd remains fairly constant over time (personal interviews with ranchers). And so, the effect of the average age of the mother cows on yearly herd average calf weaning weight is considered to be a ranch fixed effect normalizing over time.

Interaction effects between age of dam and sex on weaning weight of calves has been found to be insignificant (Minyard & Dinkel, 1965). Others assumed that interactions between these and other factors such as sire[8] and season of calf birth were insignificant and therefore didn't incorporate them into their analysis (Brown, 1960).

[8] The sire is the bull that was used to breed the cows.

Supplemental Feeding

By increasing the fat intake of prenatal cows, supplemental feeding practices have proven to be favorably influential on increasing weight gain and birth weights of beef calves (Dietz, et al., 2003; Havstad, McInerney & Church, 1989). Pregnant cows fed predominately rations of high energy corn or dried distillers grains have been shown to 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 have concluded though 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 individual feeding regimens over the time period of this study (personal communication with ranchers). The variation of idiosyncratic grazing practices and their potential effect on CWG across sample ranches is captured by the fixed-effects for each ranch (ranch fixed effects) incorporated into the estimation model.

Calf Breed

Calf breeds have proven to be a determining factor in the growth and body weight of pre-weaned beef cattle (Wiltbank, et al., 1966; Gregory, et al., 1965). Using a sample of Angus and Hereford cattle, some researchers have found that heifer Hereford calves were heavier than heifer Angus calves at time of weaning (8 months of age) (Brown, Brown & Butts, 1972) while others have shown that differences in weaning weights between Angus and Hereford were insignificant (Minyard & Dinkel, 1965). The potential effect of breed on CWG is controlled for in the estimation model with the use of calf breed discrete variables.

Genetic Selection

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). Other traits of calves such as 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). Also, different breeds and crossbreeds of calves yield varying conception and calving intervals which influences breeding and calving times (Doren, Long & Cartwright, 1986).

Ranchers self-select sires and mother cows based on genetic traits which yield calves with varying qualities (i.e. birth weight, weaning weight, temperament, etc.) specific to individual producer tastes. Through genetic selection of sire traits, over time there is the potential for producers to yield calves with lighter birth weights but show increased growth rates compared to non-selective sires (Arnold, et al., 1990). Though the genetic selection of cattle herds differ across ranches, it is assumed the effect of genetic variation on average calf weaning weight will be a long-term trend normalizing over time and captured by the ranch fixed effects incorporated into the estimation model.

Hormone Implanting

Some calf producers chose to implant their calf herd with growth hormones to stimulate weight gain which has been show to increase average daily weight gained by calves by 20%

(Burroughs, et al., 1954). Average daily weight gain of finishing steers[9] has been shown to be increased by 16% (Rumsey, et al., 1996) and as much as 23% (Kahl, Bitman & Rumsey, 1978) when implanted with a growth hormone (Synovex-S[10]) compared to steers with no growth hormones of similar physical character and raising conditions. Other researchers have reported similar results of increased weight gain trends of finishing steers due to the effect of the growth hormone Synovex-S (Dimius, et al., 1976; Embry & Gates, 1976; Rumsey & Oltjen, 1975). Disparity in the magnitude of the effect growth hormones have on average daily weight gained by calves may have to do with differences in timing of implanting during the growing stages of the calves as well as dosage amounts (Hunt, et al., 1991).

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).

Environmental Factors

Differences in environmental rearing conditions of beef calves can have an impact on the way in which they gain weight. Stress on calves induced through a multitude of factors such as heat, cold, dampness, wind, injury, insufficient forage intake, exhaustion, and escalated levels of exertion due to handling can negatively affect CWG (Rinehart, 2006). Environmental

[9] 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.
[10] Synovex is an implant containing estradiol and progesterone used to boost weight gain of calves during the growing and finishing process of cattle production

factors are most influential on CWG during the first 12 months of a calf's life (Brown, Brown & Butts, 1972) such as increased severity of weather during the initial days after birth which has been shown to negatively affect both calf survival rate and weight gain (Azzam, Kinder, Nielsen, et al., 1993). Analyzing a time extensive data set, researchers found that extreme weather during calving season negatively impacts the growth trends of beef calves (Beffa, van Wyk & Erasmus, 2009).

Increased stress on cattle induced by extreme weather has been show to negatively affect the physical productivity of the animals. Friesian[11] calves exposed to three consecutive days of high ambient heat have, as a result, been shown to lose 15% of their body weight (Kamal & Johnson, 1971). A similar study looking at the effects of increased heat exposure on adult Friesian cows found a 27.67% decline in total body weight (Kamal & Seif, 1969). Using a simulation model of influential environmental factors on calf productivity, researchers concluded that calves gain weight at suboptimal rates during periods of decreased temperatures due to the increased use of forage intake by calves for energy production to stay warm (Fernandez-Rivera, Lewis, Klopfenstein & Thompson, 1989).

STOCKING DENSITY

Habitat characteristics can have an indirect impact on cow-calf ranching operations. Foraging opportunities and decisions of mother cows may have a negative indirect effect on CWG due to malnutrition. Surpassing the carrying capacity of a pasture due to overgrazing will result in less than adequate available forage for a herd (Rinehart, 2006) which can contribute to suboptimal CWG. Overgrazing of rangeland is most commonly attributed to mismanagement of

[11] 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.).

the land by the producer, but others have theorized that overuse of some foraging areas by both wild and domestic ungulates is the result of increased predation risk (Kotler & Holt, 1989).

Research on other predator-prey systems such as owls and desert rodents (Brown, et al., 1988) and stream fish (Gilliam & Fraser, 1987) has surmised that the greatest impact of predation on a prey species may not be direct depredation, but the way it changes the behavior of the prey species by giving up optimal foraging opportunities to avoid predation risk which can result in overuse of certain, non-threatening, areas.

No research is known to exist on the effect of predator presence on foraging decisions of cattle, specifically, but research on other predator-prey systems (Kotler & Holt, 1989; Brown, et al., 1988; Gilliam & Fraser, 1987) may lend credence to the possibility for there to be an effect of predator presence on cattle foraging behavior. Though sufficient resources may be available within the confines of a pasture, cattle may opt to give up optimal foraging opportunities in certain areas due to the increased predation risk they may have to endure while utilizing it. While giving up the available food in the "riskier" areas of the pasture cattle may over utilize other, less risky, areas of the pasture resulting in overgrazing.

Foraging Efficiency

Production of both wild and domestic ungulates consists mostly of forage intake (I = kg/day) (Howery & 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). 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). This theory was substantiated by observing large herbivores; as "patch" densities increase goats spend less time walking in search of food and more time eating subsequently increasing their foraging efficiency (de Knegt, Hengeveld, Langevelde, et al., 2007).

The amount of forage available to ungulates as well as the length of vegetative growing season has been shown to be positively correlated with body weight of wild ungulates such as red deer (Mysterud, Langvatn, Yoccoz & Stenseth, 2002). In some areas that experienced faster rates of vegetative green-up (early May to early July) it was found that juvenile big horn sheep lambs grew at a slower rate than in areas that had a slower, more gradual vegetative green up period (Pettorelli, Peletier, Hardenberg, et al., 2007). The researchers theorized although areas with extreme rates of vegetative green-up may produce higher plant productivity, it may also lead to a shorter time period of available high-quality forage in a large spatial area. This would decrease the ability for the wild ungulates to utilize all of the available food before it dried up and became less palatable. Other research has produced similar results concluding that wild ungulate such as elk (Hebblewhite, Merrill & McDermid, 2008) and alpine reindeer (Pettorelli, Weladji, Holand, et al., 2005) in areas with longer more gradual growing seasons are heavier in terms of body mass relative to those in areas with faster, more extreme vegetative green-up rates.

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). Various studies have demonstrated this behavior in different prey species such as gerbils (Kotler, Brown & Hasson, 1991), fox squirrels (Brown & Morgan, 1995), and Nubian ibex (Kotler, Gross & Mitchell, 1994). Effects of predator presence may reach beyond the direct depredation of prey species by indirectly affecting their behavior through increasing time allotted to habitat selection (Kotler & Holt, 1989), which may in turn affect foraging efficiency and weight gain rates.

With the added threat of predation on the landscape prey must balance that risk with their need for nutrient intake and maximizing foraging efficiency. Dubbed the "landscape of fear," researchers propose 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 aquatic insects (Sih, 1980) as well as mule deer under predation risk of mountain lions (Altendorf, Laundre, Lopez Gonzalez & Brown, 2001).

The incorporation of a predator species to a habitat that was previously a safe-haven for prey has been shown to increase the vigilance levels of prey species. Studying the behavior of impalas and wildebeest after the reintroduction of lions and cheetahs into the study area, researchers concluded the level of vigilance went up by over 200% in both prey species due solely to the increased threat of predation (Hunter & Skinner, 1998). Hunter & Skinner (1998) added that even during significant periods of subdued cheetah and lion presence, both prey species did not decrease their heightened level of vigilance thus continuing to forage at suboptimal rates.

Allotting less time foraging in favor of looking for possible threats on the landscape curtails the amount of time allotted to nutrient intake. A potential indirect effect culminating from the perceived threat of predation is sub-optimal physical production levels such as decreased weight gain of the prey species (Howery & DeLiberto, 2004). Substantiating this finding, female elk with calves in areas with wolves increased their rates of vigilance from 26.4% in year one of the study to 47.5% during the second year compared to mother elk residing in areas with no wolves that had vigilance rates of around 20% across both years (Laundre, Hernandez & Altendorf, 2001). The researchers also found a relationship between increases in vigilance rates and a decline in time spent foraging. These findings infer that when mother elk perceive a threat from the presence of predators they spend more of their time in a vigilant state and less time foraging which may negatively influence production levels of both the mother and nursing calf. Other research comparing cows and elk directly suggests that cattle may be more susceptible to similar risk effects than wild herbivores such as elk (Muhly, Alexander, Boyce, et al., 2010).

Herd size and its effect on foraging efficiency and rate of vigilance has been a heavily debated topic with no clear conclusion (Elgar, 1989). Various authors have found a negative correlation between herd 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 a significant group-size effect in their research.

In some regions of Montana, cattle compete with wild ungulates such as elk, deer, and moose for vegetative forage. This competition for similar dietary resources can decrease the amount of forage available for cattle on a given grazing allotment (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). The potential habitat locations offered to wild ungulates such as elk, moose, and deer are limited only by their willingness to travel, but that of domesticated livestock such as cattle are restricted by fences, deeded land, and leases. If the "optimal" habitat created by the "landscape of fear" (Laundre, Hernandez & Altendorf, 2001) is found within the confines of a fenced pasture for both domestic and wild ungulates, the effects of overgrazing may be escalated. The subsequent decreased amount of available forage could potentially contribute to suboptimal CWG.

METHODS

Ranch Specific Data Collection Process

The target study area for this project was western Montana over the years 1995-2010. To obtain a population pool of ranchers from which to sample, the help of two agricultural associations was sought—the Montana Cattlemen's Association (MCA) and the Montana Stockgrowers Association (MSA). The main obstacle encountered when working with these groups was finding a way to work with the respective membership lists without compromising the confidentiality agreements each organization has with its members. Both the MCA and MSA have an agreement with their members that any personal information obtained by the association will not be disclosed to anyone outside of the association. Because I did not have unrestricted access to the information on the lists—names, phone numbers, addresses, email addresses, etc.—a process was derived to contact members from the respective associations while complying with the given confidentiality agreements via email and a website.

Initially, attempts to contact prospective participants were made by email. An email was drafted with a short description of the project and what was being asked from cow-calf ranchers in western Montana (See the Appendix: Figure 1 for a copy of this email). If contacted ranchers decided to participate in the study they had the opportunity to provide me personally with their contact information through a website.

With the help of the Information Technology (IT) department on campus, a website was launched designed specifically for ranchers to provide their contact information via a link to the website in the email. [12] Once a rancher submitted their information via the website, an email

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[12] I want to thank James Robertson in the IT department at the University of Montana for his role in constructing and getting this website online for us.

was sent directly to me containing the information provided by the producer which was used to make contact with them (See the Appendix: Figure 2 for a snapshot-image of the "contact information page" of the website).

In May of 2010, I worked with the president of the MCA, Kim Baker, to send out the first emails to members of the MCA. Members of the MCA are spatially categorized into 9 districts across the state of Montana (See the Appendix: Figure 3 for MCA district map). Using a random number generator in Excel (Microsoft Office Excel 2007) current members of the MCA (as of 2009) from districts located in the western part of the state who had email addresses on file with the MCA were sampled to receive the email. I sent a total of 133 emails to members of the MCA. A breakdown of the distribution of emails sent to MCA members is displayed as Table 1 below.

TABLE 1: EMAILS SENT TO MCA MEMBERS

MCA DISTRICT	# OF EMAILS	NOTES
1	21	ALL MEMBERS IN DISTRICT WITH EMAIL ON FILE WITH MCA
2	23	ALL MEMBERS IN DISTRICT WITH EMAIL ON FILE WITH MCA
3	29	ALL MEMBERS IN DISTRICT WITH EMAIL ON FILE WITH MCA
4	30	RANDOM SAMPLE OF MEMBERS IN DISTRICT WITH EMAIL ON FILE WITH MCA
6	30	RANDOM SAMPLE OF MEMBERS IN DISTRICT WITH EMAIL ON FILE WITH MCA
TOTAL	**133**	

Later in May of 2010, working with Jay Bodner, the Director of Natural Resources for the MSA, an email similar to the one sent to members of the MCA was sent to sampled members of the MSA. A total of 120 emails were sent to members of the MSA who had email addresses on file with the organization. A breakdown of the spatial distribution across the state is displayed below as Table 2 (See Appendix: Figure 4 for the MSA district map). Two weeks after the initial email was sent, Jay Bodner sent out a follow-up email to the randomly selected MSA members to remind them of the opportunity to participate in the study.

TABLE 2: EMAILS SENT TO MSA MEMBERS

MSA DISTRICT	# OF EMAILS	NOTES
WESTERN	40	RANDOM SAMPLE OF MEMBERS IN DISTRICT WITH EMAIL ON FILE WITH MSA
NORTH CENTRAL	40	RANDOM SAMPLE OF MEMBERS IN DISTRICT WITH EMAIL ON FILE WITH MSA
SOUTH CENTRAL	40	RANDOM SAMPLE OF MEMBERS IN DISTRICT WITH EMAIL ON FILE WITH MSA
TOTAL	**120**	

After a month, contact information from 4 ranchers was received in response to the emails via the website. A *prior* concern of the sampling process was that many of the people in the target population may not use email on a regular basis or at all. Because of the very limited response rate, a hard copy of a letter describing the project asking for rancher participation was sent out to the randomly sampled ranchers (See the Appendix: Figure 5 for a copy of this letter). Included in each letter was a self-addressed stamped envelope and card where the rancher could provide their contact information (see the Appendix: Figure 6 for a copy of the information card). If the recipients of the letter decided to make themselves available for participation in the study they would fill out the information card and mail it to me using the self-addressed stamped envelope provided. The first letters sent to prospective participants were mailed in June of 2010. Working again with Jay Bodner, 120 letters were sent to the same MSA members in districts 1, 2, and 3 who were randomly sampled to receive the original email.

Along with the MSA, other agricultural organizations were used as additional channels to get letters out to ranchers in Montana to bolster the potential pool of participants in the study.

Working with local chapters of the MSA and various Montana State University (MSU) County Extension Agents more letters were sent out during the summer and early fall of 2010. As was the practice with the MCA and MSA direct access to membership lists and list serves of these groups was not allowed. The process of sending letters followed with these organizations paralleled that of the one used with the MCA and MSA described previously. Instead of randomly sampling from the local subsidiary groups, letters were sent to every current member of each organization. Table 3 below displays which organizations I worked with; who I worked with in the organization; where the organizations are headquartered in Montana; and how many letters were sent out.

TABLE 3: DISTRIBUTION OF LETTERS MAILED OUT

ORGANIZATION	CONTACT	LOCATION	# OF LETTERS
CRAZY MOUNTAIN STOCKGROWERS ASSOCIATION*	JED EVJENE	BIG TIMBER	35
GALLATIN BEEF PRODUCERS*†	RON CARLSTROM	BELGRADE	115
PARK COUNTY STOCKGROWERS ASSOCIATION*	JAMIE LANNEN	LIVINGSTON	35
MADISON-JEFFERSON COUNTY MSU EXTENSION OFFICE†	ANDREA SARCHET	WHITEHALL	210
BEAVERHEAD COUNTY MSU EXTENSION OFFICE†	J.P. TANNER	DILLON	120
POWELL COUNTY MSU EXTENSION OFFICE†	JODI PAULEY	DEER LODGE	58
			TOTAL 573

* CONTACT WAS THE PRESIDENT OF THE RESPECTIVE ORGANIZATION AT TIME OF DATA COLLECTION
† CONTACT WAS THE MONTANA STATE UNIVERSITY EXTENSION AGENT FOR THE RESPECTIVE COUNTY(S)

MSU Extension service does not work exclusively with cattle producers in Montana. The mission of the MSU Extension service is to provide all Montanans with research-based knowledge to better educate them while making informed decisions in their lives (Montana State University Extension, n.d.). Anyone interested in the various services the MSU Extension service provides can be part of their respective MSU county extension agent's mailing list. Because working with Montana cattle producers is only a portion of what the MSU Extension service does, many of the lists used to send out letters consisted only partly of cattle producers. The total number of letters sent out through the various organizations in the above table (573 letters) may overestimate the total cattle producers in the target population who received letters asking for participation in this project.

Once a producer received a letter and decided to be available for participation in the project, they were contacted to set up an on-ranch meeting. The purpose of the meeting was twofold. First, the personal interview was used to collect ranch specific data such as yearly average weaning weights and ranch specific husbandry practices. Second, it is imperative that any measureable change in husbandry practices on a sample ranch over the time period is accounted for. Anything that was changed—such as breed of the calves, calving dates, hormone programs, etc.—that could have a direct influence on the weaning weight of the rancher's respective calves needed to be documented. To account any changes or idiosyncratic practices novel to the ranch in question, it was necessary to personally go to the ranches and sit down to talk about the ranchers' production operations and what was being asked of them for the purpose of this study. Out of 826 letters mailed out, we had 54 (6.54%) people responded back to participate in the study. Some respondents did not qualify for participation (i.e. didn't 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 interviewed.

ESTIMATION MODEL

The data were analyzed using a linear ordinary least squares (OLS) model. Other researchers have used OLS procedures to describe variation in calf weight (Dal Zotto, et al., 2009) and to analyze the effects of calf sex (Barlow, Dettmann & Williams, 1978), genetic and environmental factors (Brown, Brown & Butts, 1972), and other covariates (Cundiff, Willham & Pratt, 1966) on calf weight gain. The OLS estimation model used in the analysis regresses average calf weaning weight (*calf_weight*) on all measurable covariates believed to have an influence on calf weight gain (CWG) from the time they are born to weaning. The regression model is displayed as Equation 1 below:

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

Equation 1

where *calf_weight* is normally distributed (Shapiro-Francia W' = .99668; p ≈ .45) and measured as the average weaning weight (or sale weight) of calves on 18 sample ranches over 16 years. To capture all unobserved characteristics that are inherent to individual ranches (such as unobserved husbandry habits, ranch terrain characteristics such as slope and elevation, ranch geography and location in the state, etc.) that may influence CWG but do not change over time, ranch specific fixed effects for each of the 18 sample ranches are included in the model. The net effect of these unobserved ranch effects are captured by the ranch specific coefficients $\boldsymbol{\alpha_i}$.

To control for any unobservable changes over time (1995-2010) that are common across ranches in the sample (such as state or federal policies, changes in industry norms, feed quality, vaccination products, etc.) that may influence CWG, year fixed effects are included which capture these net effects by the $\boldsymbol{\alpha}_t$ coefficients.

The model also includes a vector of variables, $\mathbf{x}_{it}\boldsymbol{\beta}$, that change both over time and across sample ranches. A portion of the data used to account for factors that change overtime and across ranches that may influence CWG was collected during on-ranch interviews. A pre-drafted questionnaire was used during the on-ranch interview process as a guideline for data collection on sample ranches[13] (See the Appendix: Figure 13 for a copy of the questionnaire).

The sample used in the analysis consists of 437 observed annual average calf sale weights (which is generally at the same time as weaning) across 18 Montana ranches over a 16 year period (1995-2010). It should be noted that three initially interviewed ranches were not used in the analysis. One ranch provided only 7 observations of *calf_weight* over 6 years which was insufficient to accurately account for unobserved across ranch and year variation in the dependent variable. The other two omitted ranches did not separate male and female calves before weighing. Due to this, the sample calf weight observations provided by these ranches are representative of both steer and heifer calves, but an accurate distribution of each sex within each observation is unknown across time. Because of this known bias in the variation of *calf_weight*, the respective ranches (which account for 28 observations) are omitted from the analysis. The ranch-year specific covariates compiled using the rancher questionnaires are displayed in Table 4.

[13] The rancher questionnaire and project proposal was submitted to the University of Montana's Institutional Review Board (IRB) for approval before any data collection was commenced. IRB deemed that the research done in this project does not need IRB review or approval because the study does not fall into the category of "research involving human subjects" as defined in 45 CFR 46.102(d).

TABLE 4: RANCH-YEAR SPECIFIC DATA COLLECTED DURING ON-RANCH INTERVIEWS

AVERAGE WEANING WEIGHT	**HORMONE IMPLANTING**
STEER CALVES	STEER CALVES
HEIFER CALVES	HEIFER CALVES
BREED	**ARTIFICIAL INSEMINATION**
CALVES	**APPROXIMATE NUMBER OF CALVES SOLD**
SIRES	**IF CALVES ARE REGISTERED PUREBRED**
MOTHER COWS	**USE OF RANGE RIDERS**
CALVING SEASON	**YEARS RANCHER FELT WOLVES WERE AROUND**
APPROX. DATE OF FIRST CALF BORN	**WOLF DEPREDATION**
APPROX. DATE OF LAST CALF BORN	CONFIRMED BY WILDLIFE SERVICES
CALF WEANING DATE	PROBABLE BY WILDLIFE SERVICES
APPROX. # OF ACRES USED FOR PASTURE	SUSPECTED BY RANCHER

CALF SEX—The sex of the calf has been shown to have an effect on CWG and weaning weight (Barlow, Dettmann & Williams, 1978). Looking at Table 5, the dependent variable in the estimation model, *calf_weight*, is 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 of *calf_weight.*

TABLE 5: BREAKDOWN OF OBSERVATIONS IN THE SAMPLE

YEAR	STEER	HEIFER	TOTAL
1995	8	7	15
1996	8	8	16
1997	9	8	17
1998	12	12	24
1999	14	13	27
2000	16	15	31
2001	16	15	31
2002	16	16	32
2003	17	16	33
2004	17	16	33
2005	17	15	32
2006	17	16	33
2007	17	15	32
2008	17	16	33
2009	17	16	33
2010	8	7	15
TOTAL	**226**	**211**	**437**

WEANING WEIGHT—Average yearly calf weaning weights in the sample range from 461 to a maximum of 809 pounds with an average weight of 650.96 (SD = 60.3883) and 600.16 (SD = 58.4309) pounds for steers and heifers, respectively (Table 6).

TABLE 6: SUMMARY STATISTICS: RANCH-YEAR CONTINUOUS VARIABLES

	# OF OBS.	MEAN	STD. DEV.	MINIMUM	MAXIMUM
AVERAGE WEANING WEIGHT (LBS.)					
STEER CALVES	226	650.96	60.3883	478	809
HEIFER CALVES	211	600.16	58.4309	461	749
AVERAGE AGE OF CALVES (DAYS)	437	240.33	33.3886	160	347
NUMBER OF CALVES SOLD	437	263.70	261.7169	65	1300

Looking at sample steer and heifer weights over time (Figure 1), on average, weights steadily increase through the period of 1995 to around 2002. With the exception of a spike in 2004, on average calf weights in the sample seem to be steadily declining through 2010.

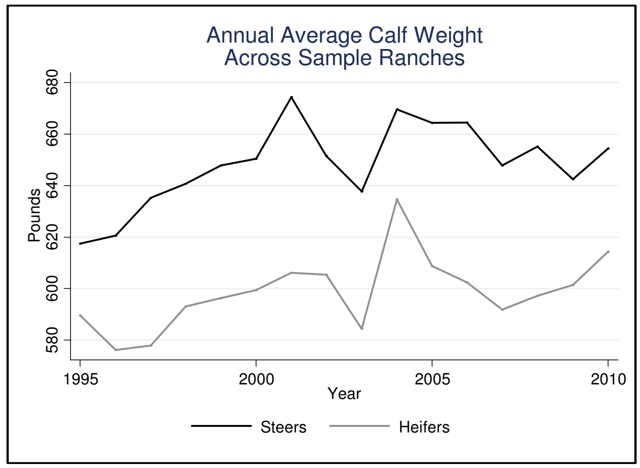

Figure 1

AGE OF CALVES—Researchers have shown through linear regression of age (days) of a calf on weaning weight (pounds) of a calf is equal to as much as 1.46 pounds per day (Botkin & Whatley, 1953) with others finding coefficients of 1.33 pounds (Koger & Knox, 1945) and 1.20 pounds (Minyard & Dinkel, 1965) per day. During calving season on a ranch the distribution of calves born over time is roughly bell shaped centered on the middle of the calving season (Minyard & Dinkel, 1965).

This study uses a calculated average age of sample calves in days (*calf_age*) to account for the effect age has on calf weaning weight. *Calf_age* is representative of 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 (Table 4) for each ranch *i* in year *t.* Using the calculated average median

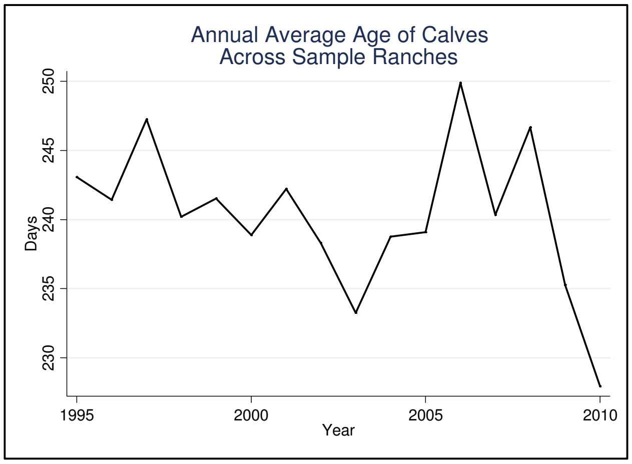

Figure 2

birth date and weaning date (Table 4) an average age (in days) of the calves on ranch *i* in year *t* was calculated. Calves in the sample range in age from 160 days to 347 days and average 240.33 (SD = 33.3886) days old (Table 6). On average, across ranches variation in the age of calves over time is seemingly random over the time period of the study (Figure 2).

Stocking Density—Surpassing the carrying capacity of a pasture due to overgrazing will result in less than adequate available forage for a herd (Rinehart, 2006) which can contribute to suboptimal CWG. To control for the potential effect of stocking density on CWG, the yearly approximate number of calves sold by each sample ranch is used in the estimation model. There were approximately 263.70 (SD = 261.7169) calves sold by the average sample ranch with a range from 65 to 1300 calves sold (Table 6). After peaking in 1998 at just over 320 calves, on average, the number of calves sold by sample ranches declines through 2010 to fewer than 220 calves (Figure 3).

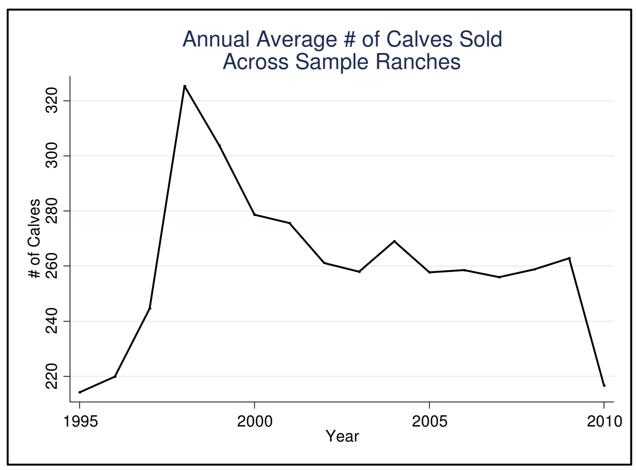

Figure 3

TABLE 7: SUMMARY STATISTICS: RANCH-YEAR DISCRETE VARIABLES

VARIABLE	FREQUENCY	PERCENT
CALF BREED		
BLACK ANGUS	182	41.65
BLACK ANGUS/CHARLET	36	8.24
BLACK ANGUS/HEREFORD	102	23.34
BLACK ANGUS/SALERS	22	5.03
BLACK ANGUS/SIMMENTAL	24	5.49
HEREFORD	15	3.43
RED ANGUS	15	3.43
RED ANGUS/CHARLET	4	.92
RED ANGUS/HEREFORD	15	3.43
RED ANGUS/SIMMENTAL	22	5.03
TOTAL	437	100
HORMONE IMPLANTING		
YES	150	34.32
NO	287	65.68
TOTAL	437	100
ARTIFICIAL INSEMINATION		
YES	37	8.47
NO	400	91.53
TOTAL	437	100
REGISTERED PUREBRED		
YES	39	8.92
NO	398	91.08
TOTAL	437	100
RANGE RIDERS		
YES	34	7.78
NO	403	92.22
TOTAL	437	100

CALF BREED—Some studies have shown that breed is a determining factor in the growth and body weight of pre-weaned cattle (Wiltbank, et al., 1966; Gregory, et al., 1965), although others have found that differences in weaning weights between certain breeds are insignificant (Minyard & Dinkel, 1965). This study incorporates the breed of calves in the sample to control for any possible effects breed has on CWG. Ten different breeds of calves are observed in this study with the most prevalent being Black Angus (Table 7: *Calf Breed – Black* Angus = 182 observations).

Hormone Implanting—Although approximately one third of sample observations use hormone implanting (Table 7: *Hormone Implanting – Yes* = 34.32%), on average, over time fewer and fewer ranchers in the sample opted to use growth hormones in their calves (Figure 4).

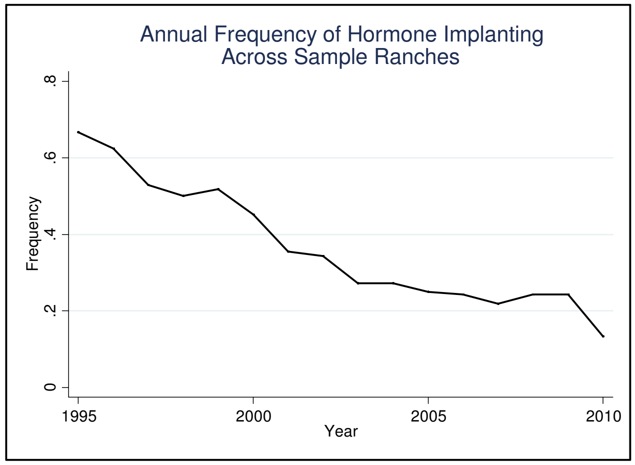

Figure 4

Other Discrete Covariates—The majority of sample observations did not use artificial insemination for breeding of mother cows (Table 7: *Artificial Insemination – Yes* = 8.47%), are not registered as purebred calves (Table 7: *Registered Purebred – Yes* = 8.92%), or didn't use range riders during the time calves were on summer pasture (Table 7: *Range Riders – Yes* = 7.78%). If a ranch implemented the use of "range riders," they had hired people in and around the cattle (generally on horseback) almost every day while the cattle were grazing on summer pasture.

Ranch Fixed Effects

The spatial aspect of where calves resided during the years in question is pivotal in the analysis of this project. Information was gathered during on-ranch interviews about where sample calves were pastured during the summer and if that changed over the time period of interest. None of the 18 ranches in the sample changed pasture size or spatial location over the study's time period (Personal communication with producers). After personal communication with the rancher about the location of their herd during the summer, the Montana Cadastral Database[14] was used to create a spatial representation of where the calves were located.

Ultimately, an interactive map was created delineating each individual sample ranch summer pasture using ArcGIS 9 (A product of ESRI; ArcEditor 9.3.1 and Extensions: Education Edition). Using the Montana county cadastral property ownership files,[15] the parcels of land a sample ranch used to pasture its calves from 1995-2010 was selected. The selected parcels were then made into a map for the respective sample ranch. Once a land map for all ranches in the sample was created, the individual maps were merged together creating a spatial representation of all land used for summer pasture of calves categorized by each sample ranch.[16] When talking about sample "ranches," it is in reference to the land used by the ranches in the sample to pasture their calves during the summer and early fall over the time period of the study (summer pasture). Summer pasture for the ranches in the sample consists of a combination of deeded, privately, and publicly leased land (See the Appendix: Figure 7 for a map of summer pasture used by ranches in the sample).

TABLE 8: SUMMARY STATISTICS: RANCH FIXED EFFECTS

	MEAN	**MEDIAN**	**STD. DEV.**	**MINIMUM**	**MAXIMUM**
RANCH SIZE (ACRES)	14235.38	4240	19718.78	2000	64000
RANCH ELEVATION (FEET)	1617.85	1574.15	298.186	1154.93	2188.59
RANCH SLOPE (DEGREES)	8.58	6.55	4.437	1.82	20.41

N = 18 RANCHES

[14] 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.

[15] The "OwnerParcel" Personal Geodatabase Feature Class within the "ParcelFeatures" Personal Geodatabase Feature Dataset of each county cadastral data file was used as base data for creating maps.

[16] All cadastral data polygons use the same Projected Coordinate System: NAD_1983_StatePlane_Montana_FIPS_2500

To get a sense of the geographic characteristics of the sample ranches, some measurable features of the ranch fixed effects used in the estimation model ($\boldsymbol{\alpha}_i$) are represented in Table 8 above. The average ranch in the sample is 14235.38 (SD = 19718.78) acres with an expansive range from 2,000 to 64,000 acres. Ranging from a minimum of 1,154.93 to 2,188.59 feet the average sample ranch is 1,617.85 (SD=298.186) feet above sea level. The mean slope of ranches in the sample is 8.58 (SD=4.437) degrees ranging from 1.82 to 20.41 degrees.[17]

CLIMATE VARIABLES

Calves are most vulnerable to factors that influence weight gain during their first year of life (Brown, Brown & Butts, 1972). During the first year of a calf's life the severity of weather conditions such as increased ambient temperatures (Kamal & Johnson, 1971) and increased precipitation along with decreased ambient temperature (Azzam, et al., 1993) has been shown to negatively affect CWG (Rinehart, 2006). Average temperature and aggregate snowfall and precipitation measures are used in the estimation model of *calf_weight* (Equation 1) to capture climactic effects on CWG.

Raw data on monthly average temperature and aggregate rainfall and snowfall was obtained from the Western Regional Climate Center's (WRCC) website[18] to control for climatic variation on sample ranches over the time period of the study. Working with the Cooperative Observer Program (COOP), the National Weather Service (NWS) has weather stations located across Montana. NWS volunteers across the state gather daily meteorological data at over 700

[17] Average elevation and slope were estimated using a 30 meter pixel resolution digital elevation model obtained from Montana Cadastral Mapping (http://gis.mt.gov).

[18] 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/

different locations which is then cataloged and made available for public use (Cooperative Observer Program Fact Sheet, 2010).

To control for weather conditions on a particular ranch in the sample, the spatially closest COOP station to the ranch was located and the meteorological data from the respective station is used to account for the monthly average temperature, aggregate rainfall, and snowfall on the ranch in the analysis. A map[19] was created delineating the COOP station locations in Montana using the provided latitude and longitude coordinates on the WRCC website of each station using ArcGIS 9 (A product of ESRI; ArcEditor 9.3.1 and Extensions: Education Edition). The COOP weather station map was then overlaid onto the map of the sample ranches to find the weather station located closest to each ranch using the linear distance measurement tool. A map of the Montana COOP weather stations can be found in the Appendix: Figure 9.

Some COOP weather stations either didn't have any meteorological data available online or didn't have data spanning the time period needed for this study. In these cases, the weather station located closest to the ranch that had available data online for the time period of interest is used for analysis. The monthly COOP climate data provide online is a calculation comprised of daily measurements observed by the respective COOP weather stations. Some monthly average and aggregate weather figures provided by the COOP are calculated with some missing daily observations. The total number of missing observations used in the calculation of each monthly weather figure is provided by the COOP. If there was an increased number of missing daily measurements used to calculate a COOP monthly weather figure, the

[19] Shapefile was created using the Geographic Coordinate System: GCS_North_America_1983_CSRS

respective monthly climate COOP observation is replaced in the analysis with an interpolated observation.

A threshold of no more than five missing daily observations was used for purposes of interpolating the monthly aggregate precipitation and snowfalls figures. If any monthly aggregate precipitation or snowfall COOP figure was calculated using more than five missing daily observations that month's figure was interpolated by averaging the month before and after the one in question in year *t*. If either of the months needed for interpolation were also calculated using more than five missing daily observations the month in question was interpolated by averaging the month's figure for $year_{t-1}$ and $year_{t+1}$. For example, if the aggregate snowfall for the month of March 1999 was calculated by the COOP with 8 missing days of snowfall measurements within the month, March's aggregate snowfall figure would be interpolated for 1999. Interpolation was done by averaging the aggregate snowfall in February and April of 1999 unless either of those two months' figures was also calculated by the COOP with more than 5 missing daily snowfall observations. If, let's say, April 1999 was calculated by the COOP using 6 missing observations I would interpolate the snowfall figure for March of 1999 by averaging the aggregate snowfall in March of 1998 and 2000.

The data for temperature are monthly average instead of aggregate figures so a more lenient threshold of no more than 12 missing observations was used. If a monthly average temperature figure supplied by the COOP was calculated using more than 12 missing daily temperature observation the month's figure was interpolated following the same process used for the aggregate precipitation and snowfall figures explained above.

A total of 3,072 raw monthly climactic measures were gathered for each of the three measures (*temperature, precipitation, and snowfall*) from the COOP website[20]. Of those figures, 50 (1.63%) measures of monthly average temperature are interpolated, 71 (2.31%) measures of monthly aggregate precipitation are interpolated; and 92 (2.99%) measures of monthly aggregate snowfall are interpolated for use in the analysis.

Raw monthly climactic data gathered from the COOP weather stations is used to calculate yearly average temperature, aggregate precipitation, and aggregate snowfall. Because the dependent variable (*calf_weight*) is a measure of *yearly* average calf weights, yearly average and aggregate meteorological measures are used in the estimation model to control for climactic change across sample ranches and time.

TABLE 9: SUMMARY STATISTICS: CLIMATE VARIABLES

	MEAN	**STD. DEV.**	**MINIMUM**	**MAXIMUM**
ANNUAL AVERAGE TEMPERATURE (DEGREES F)	43.432	3.0348	35.321	49.28
ANNUAL AGGREGATE PRECIPITATION (INCHES)	16.186	5.5685	5.98	33.07
ANNUAL AGGREGATE SNOWFALL (INCHES)	65.124	49.6647	0	263.5

N = 437

On average, the annual average temperature on sample ranches ranges from a low of 35.321 to a maximum of 49.28 degrees with a mean temperature of 43.432 (SD = 35.321) degrees Fahrenheit (Table 9). Ranches in the sample, on average, experienced an annual aggregate precipitation level of 16.186 (SD = 5.5685) inches ranging from 5.98 to 33.07 inches (Table 9). And sample ranches averaged 65.124 (SD = 49.6647) inches of annual aggregate snowfall with an expansive range from 0 to 263.5 inches.

[20] 16 different COOP weather stations are used to control for climactic variation on ranches across time (some weather stations are used for more than one sample ranch due to spatial proximity). Total raw monthly climactic measures = 3,072 = (12 months) x (16 years) x (16 COOP stations).

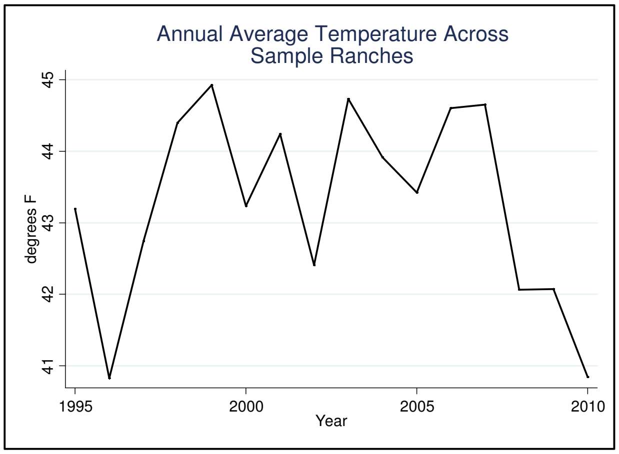

Figure 5

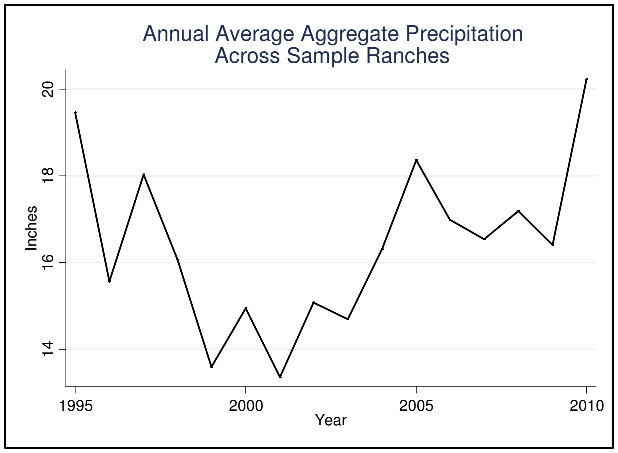

Figure 6

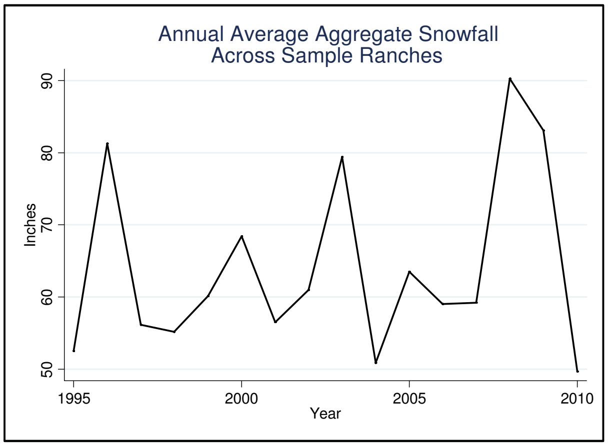

Figure 7

There is quite a bit of variation in annual average temperature, aggregate precipitation, and aggregate snowfall across sample ranches over time which is apparent in Figures 5, 6, and 7, respectively.

NORMALIZED DIFFERENCE VEGETATION INDEX

Production of both wild and domestic ungulates consists mostly of forage intake (I = kg/day) (Howery & 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). 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). In order to account for varying vegetative conditions where calves were raised over space and time measures from a Normalized Difference Vegetation Index are used in the estimation model.

The Normalized Difference Vegetation Index (NDVI) is a widely used measure describing the "greenness or relative density and health of vegetation" on the landscape (Remote Sensing Phenology: NDVI the foundation for Remote Sensing Phenology, 2011; Pettorelli, Vik, Mysterud, et al., 2005; Thoma, Bailey, Long, et al., 2002). From 1989 to present 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 "pictures" of the earth's surface at a resolution of 1 square kilometer (Remote Sensing Phenology: NDVI from AVHRR, 2011). Using the raw satellite data, scientists use algorithms to calculate composite NDVI data which range from values of -1 to +1.[21] 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). As done by other researchers (PLM - Patuxent Landscape Model) the NDVI data used in the analysis is scaled from 0 to 200. A calculated NDVI value of -1 is equal to 0, a calculated value of 0 equals 100, and a calculated value of +1 equals 200. Any scaled NDVI values less than 100 are omitted from the analysis as they represent non-vegetative areas.

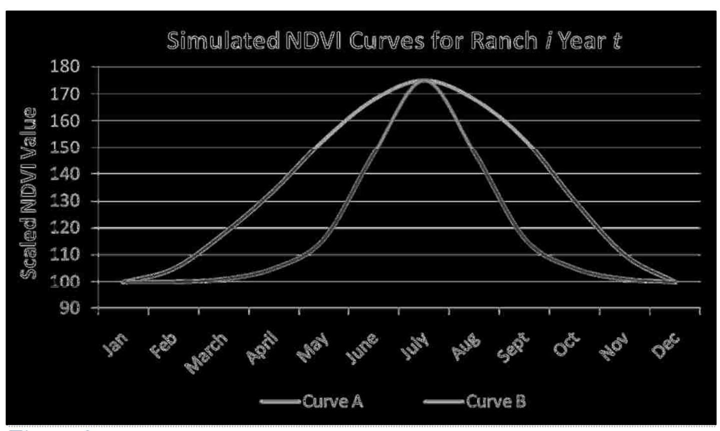

Figure 8

The NDVI data that used in this study has both a space and time component. NDVI is used in this study as a measure of forage available each

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

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* (Figure 8). 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*.[22]

Total_NDVI is representative of the integration of the "NDVI Curve" from February through November for year *t* which can be interpreted as the total amount of forage available to the cow-calf pairs on ranch *i* in year *t.* Looking at Figure 8, *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 given sample ranch over 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" (Figure 8). To measure the rate of "green-up," the standard deviation of the "NDVI curve" for ranch *i* in year *t* was calculated (*sd_NDVI).* A larger *sd_NDVI* is interpreted as having a longer growing season on the sample ranch *i* in year *t.* Looking at Figure 8 above, "Curve A" has a larger standard deviation than that of "Curve B" inferring that "Curve A" represents a longer vegetative growing season compared to that of "Curve B."

Because the dependent variable (*calf_weight*) is a measure of *yearly average* calf weight, yearly average NDVI measures (*mean_NDVI & sd_NDVI*) are used in the estimation model to control for changes in forage availability and quality across sample ranches and time.

[22] The exact start and end dates of the 6-day composites used for NDVI calculations in this study vary by a couple of days across years. The year specific exact start and end dates of the NDVI composites used in this study can be found in the Appendix: Figure 10. I want to thank Wibke Peters who calculated all NDVI data used in this study.

TABLE 10: SUMMARY STATISTICS: NDVI MEASURES

	MEAN	STD. DEV.	MINIMUM	MAXIMUM
MEAN NDVI	139.935	6.64196	125.17	163.49
STANDARD DEVIATION NDVI	14.483	3.0742	7.48	22.07

N = 437

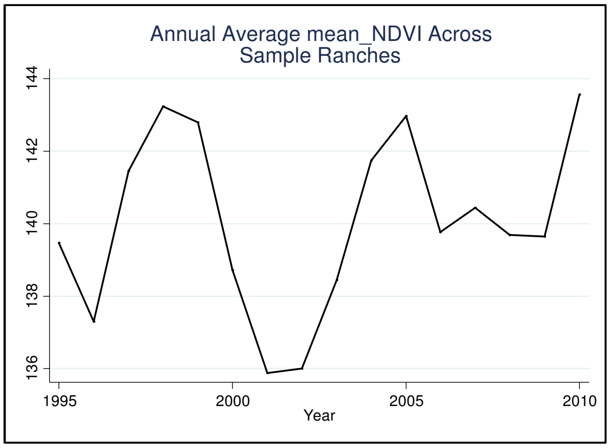

Figure 9

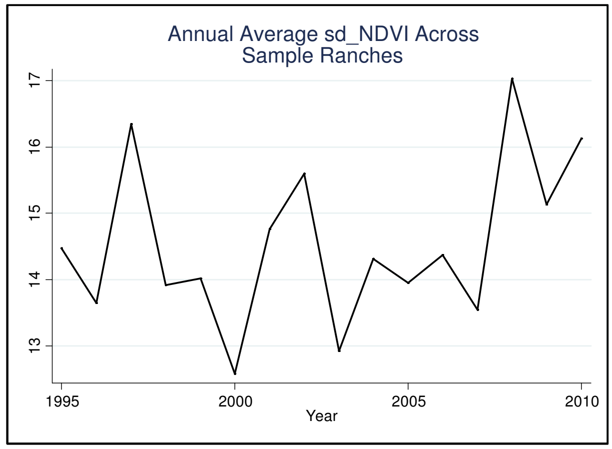

Figure 10

On average, *mean_NDVI* across ranches in the sample averages 139.935 (SD = 6.642) scaled units ranging from a minimum of 125.17 to 163.49 (Table 11). It appears that, on average, the variation in *mean_NDVI* over time is sporadic across sample ranches (Figure 9). The measure of growing season (*sd_NDVI*), on average, has a mean of 14.483 (SD = 3.0742) on sample ranches ranging from 7.48 to 22.07 (Table 11). The variation in *sd_NDVI* over time is also fairly sporadic across sample ranches (Figure 10).

WOLF PRESENCE MEASURES

After controlling for the measurable covariates that affect CWG explained above, measures of "wolf presence" on sample ranches are incorporated into the vector of variables in the estimation model ($\mathbf{x}_{it}\boldsymbol{\beta}$) to test for any effect wolves may have on CWG.

MONTANA FISH, WILDLIFE & PARKS WOLF TERRITORY MCPS

The measures of wolf presence on the sample ranches used in this study are based largely on wolf population and spatial distribution data collected through routine monitoring by United States Fish & Wildlife Services (USFWS) from 1995 – 2004 and Montana Fish, Wildlife & Parks (MFWP) from 2005 – 2010. Data for the entire period of interest was proved by MFWP.

USFWS and MFWP wolf monitoring objectives were to document new 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 delineate yearly estimated 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). MFWP is not generally involved in wolf management on Montana's Indian Reservations, but the tribes do share information pertaining to their wolf populations with the state. Some wolf territory MCPs used in the analysis are estimated based on knowledge of wolf activity provided to the state by the Flathead Indian Tribe (personal communication with MFWP's Carolyn Sime).

Though the yearly wolf MCPs are delineated using the best knowledge of wolf activity, they are not an exact depiction of wolf pack territory boundaries because of the course scale and intensity/frequency with which the wolves were monitored. Wolf packs in the Northwest

Montana Endangered Area (NWMT) are generally underrepresented in MFWP's wolf MCPs compared to those in the Greater Yellowstone Experimental Area (GYA)[23] (personal communication with MFWP's Carolyn Sime).

The MFWP's wolf pack home range MCPs used in the analysis include documented wolf packs and the number of wolves in those packs as of December 31st of the respective year (Sime, Asher, Bradley, et al., 2011) and may potentially underestimate wolf presence on sample ranches in the analysis. Packs that were either removed through state or federal agency control or disappeared for whatever reason during the calendar year are not represented in the respective year's wolf MCP map (Sime, et al., 2011). A known wolf pack may have been located on a sample ranch during the time calves were on summer pasture, but if the pack was subsequently removed or disappeared before December 31st of that year, the pack is not recognized by MFWP in the respective year's wolf MCP data and therefore not included in the analysis. The known potential for a false negative in the wolf presence measure based on MFWP's wolf MCPs used in the analysis may incorporate a bias towards underestimation of wolf presence on sample ranches in the study. Conversely, wolves do not utilize pack home ranges uniformly and lethal control may have occurred during the grazing season; these may lead to an equally likely bias towards overestimation of wolf presence on sample ranches. The magnitude of such biases is unknown and infeasible to measure (personal communication with MFWP's Carolyn Sime).

Some of the spatial characteristics of the wolf territory MCPs also do not perfectly outline true land use of wolves on the landscape. There are times when MFWP personnel know

[23] Montana is broken into 3 spatial federal wolf recovery areas: Northwest Montana Endangered Area (NWMT) and the Greater Yellowstone Experimental Area (GYA), and the Central Idaho Experimental Area (CID). A map of these areas can be found in the Appendix: Figure 11.

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" (Sime, Asher, Bradley, et al., 2011)) but there is not a radio-collared member of the pack or pair. Thus, radio telemetry monitoring is not possible and an MCP cannot be delineated. Therefore, a landscape feature is selected that represents the best approximation of where a pack spends time during key times of the year. This point is 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 along with the other verified wolf packs. These packs that are spatially represented using a buffered point creating a uniform circle are referred to as "centroids."

That being said, USFWS, MFWP, and other interagency and tribal partners expend a tremendous amount of time and resources each year tracking and documenting wolf numbers and locations, and the wolf home range maps culminated from those efforts form the best available spatial and temporal estimates of wolf presence in Montana from 1995 through 2010.

Three variations of the wolf home representations are used across all years for analysis in the model to test the robustness of the wolf data as a measure of presence: all wolf home range MCPs as estimated by MFWP including all packs represented as centroids, only wolf home ranges represented by MCPs (i.e. elimination of centroid packs), and all wolf home range MCPs with the centroid packs buffered to a total radius of 13.82 kilometers (which is an area equivalent to the estimated average home range size of a wolf pack in Montana (Rich, 2010)).

USDA Wildlife Services' Confirmed Wolf Depredations

The other measure of wolf presence used in the analysis is based on data collected on known instances of wolf depredation of livestock on sample ranches. If a Montana rancher suspects their livestock has been injured or killed by wolves or other predators, they have the option for the United States Department of Agriculture: Wildlife Services (WS) to conduct an investigation of the instance. A report of every WS incident investigation is completed which includes the conclusions drawn by the investigating agent. As recorded in each report, the agent will come to one of three conclusions: the incident is "confirmed" to be predation; it is "probable" the predation event occurred; or there is inconclusive evidence to make a decisive ruling on the cause of livestock mortality. The investigating WS personnel also determine the species of predator if it was an instance of predation.

While conducting on-ranch interviews, if ever a producer had a WS agent come to their ranch and conduct a depredation investigation (this includes all depredation investigations such as wolves, bears, mountain lions, etc.) they were asked to sign a release form giving me access to the pertinent report(s). Every sample rancher interviewed who had an incident of suspected predator depredation investigated by WS agreed to let WS give me copies of all respective reports pertaining to their ranching operation (See the Appendix: Figure 12 for a copy of the WS release form). Working with the State Director of Montana Wildlife Services, John Steuber, *all* WS depredation investigation reports (not just wolf depredation investigations) were obtained that were conducted on sample ranches over the time period of the study. All WS investigation reports conducted on sample ranches were wolf related (See Appendix: Figure 14 for a map of WS confirmed depredations). No sample ranches had any confirmed or probable WS investigations due to other predators such as bears, coyotes, mountain lions, etc.

WOLF PRESENCE VARIABLES

Two categories of measures are used to account for wolf presence (β^W) on the sample ranches in the study: discrete distance variables (**OL**) and discrete variable for Wildlife Service confirmed wolf depredations (**C**). The null hypothesis in the estimation regression is that wolf presence has no effect on CWG ($\beta^W = 0$). The alternative hypothesis is that wolf presence has a negative effect on CWG ($\beta^W < 0$).

TABLE 11: WOLF PRESENCE VARIABLES: DISCRETE MEASURES

	WOLF PRESENCE MEASURE
(C)	— CONFIRMED WOLF DEPREDATION*
(OL)	— RANCH OVERLAPS WOLF MCP OR CENTROID PACK
	TEST VARIABLES
(OL1)	— RANCH 1 KM FROM WOLF MCP OR CENTROID PACK
(OL5)	— RANCH 5 KM FROM WOLF MCP OR CENTROID PACK

* WOLF DEPREDATIONS ARE CONFIRMED THROUGH INVESTIGATION BY USDA WILDLIFE SERVICES

The first latent variable (**OL**) is defined to be 1 if one or more MFWP's wolf home range MCP or centroid pack spatially "overlaps" any ranch land used for summer pasture on ranch *i* in year *t* and zero otherwise. The interpretation of β^{OL} is the reduced form marginal effect of wolf presence from at least one wolf home range spatially overlapping sample ranches on CWG. The null hypothesis is that wolf presence measured by having at least one overlapping wolf home range MCP or centroid pack on sample ranches has no effect on CWG ($\beta^{OL} = 0$) with the alternative hypothesis being wolf presence decreases average calf weight ($\beta^{OL} < 0$).

The second latent variable (**C**) is defined to be 1 if there was *at least* one WS confirmed wolf depredation on ranch *i* in year *t* and zero otherwise. The interpretation of β^C is the reduced form marginal effect of having at least one WS confirmed wolf depredation on sample ranches on CWG. The null hypothesis is that having at least one WS confirmed wolf depredation on a sample ranch has no effect on average calf weight ($\beta^C = 0$). The alternative hypothesis is that having at least one WS confirmed wolf depredation decreases average calf weight ($\beta^C < 0$). Though OL and C are defined in distinctively different ways they are used in the estimation models as measures of the same thing—wolf presence on sample ranches (β^W).

To test the robustness of the measure of wolf presence defined above (OL), the latent variable OL is redefined so that an observation on a sample ranch spatially located within 1 (**OL1**) and 5 (**OL5**) kilometers from at least one wolf home range MCP or centroid pack is equal to 1 and zero otherwise, respectively. The robustness test variables (OL1 and OL5) test that the coefficient of the wolf presence variable (β^{OL}) is not spurious with some unidentified variable that happens to be correlated with wolves over time. The expected probability of rejecting the null hypothesis ($\beta^W = 0$) in favor of the alternative hypothesis ($\beta^W < 0$) will decrease as wolf packs that are spatially located farther away from the sample ranch are included into the analysis. The intuition is that as more wolf packs are included from further away from a ranch (and are therefore not likely having any effect on average calf weight at the respective ranch), wolves' marginal effects on average calf weight should move closer to zero, thus making it harder and harder to reject the null hypothesis ($\beta^W = 0$).

To create the robustness test variables of wolf presence on average calf weight defined above (OL1 and OL5), ArcGIS 9 was used to buffer the original MFWP's wolf territory MCPs and centroid packs by 1 and 5 kilometers, respectively. The map of sample ranches (explained above) was then overlaid onto the buffered wolf territory MCPs and centroids to create the respective robustness test variables defined above. For example, if a sample ranch is overlapped by a wolf MCP or centroid buffered by 5 kilometers then OL5 = 1 (as defined above) and zero otherwise.

As mentioned previously, the wolf presence variables based on MFWP data are estimated using the three variations of the wolf home range MCP data: all wolf home range MCPs and centroids as estimated by MFWP (***all MCPs & centroids***), only wolf home range MCPs with all centroid packs eliminated from the analysis (***all MCPs; no centroids***), and all wolf home range MCPs with the centroid packs buffered to a total radius of 13.82 kilometers (Rich, 2010) (***all MCPs; buffered centroids***).

TABLE 12: SUMMARY STATISTICS: DISCRETE WOLF VARIABLES

	Frequency	Percent
OL (*all MCPs & centroids*)		
Yes	76	17.39
No	361	82.61
Total	437	100
OL (all *MCPs; no centroids*)		
Yes	72	16.48
No	365	83.52
Total	437	100
OL (*all MCPs; buffered centroids*)		
Yes	92	21.05
No	345	78.95
Total	437	100
WS Confirmed Wolf Depredation (*C*)		
Yes	10	2.29
No	427	97.71
Total	437	100

The frequency of having a wolf home range MCP or centroid overlap a sample ranch (OL = 1) does not differ all that much across the three variations of wolf home range data (Table 12). Using all of the MFWP wolf home range MCPs and centroids in the analysis (*all MCPs & centroids*) there are 76 observations (17.39%) that have at least one wolf home range MCP or centroid overlapping the sample ranch. For the wolf presence data that does not include centroid packs (*all MCPs; no centroids*) there are 72 (16.48%) observations that have at least one MCP overlapping a sample ranch. And using the data with all MCPs and the centroid packs buffered to a total radius of 13.82 kilometers (*all MCPs; buffered centroids*), there are 92 (21.05%) observations with at least one wolf home range MCP or buffered centroid pack overlapping the sample ranch.

As with the total number of observations, on average, the three variations of wolf home range MCP and centroid data yield very similar trends in the percentage of observations in the sample over time that have at least one MCP or centroid overlapping the sample ranch (Figure 11). It appears that, on average, the number of observations in the sample with at least one wolf home range MCP or centroid overlapping the sample ranch (OL = 1) is increasing over time. As the wolf presence variable (OL) is defined, the interpretation of this trend is that as time goes on more and more calves in the sample are experiencing wolf presence while on summer pasture.

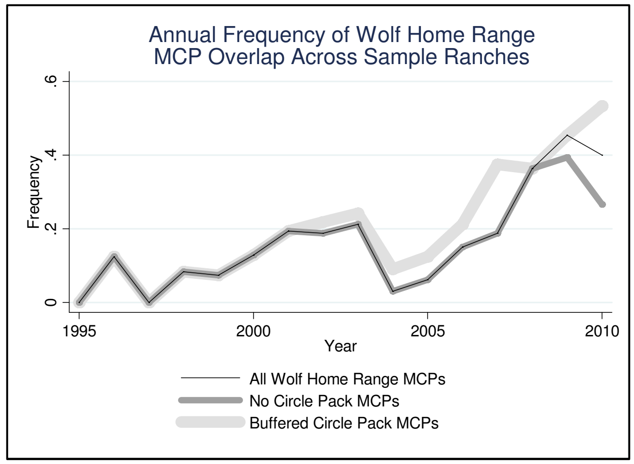

Figure 11

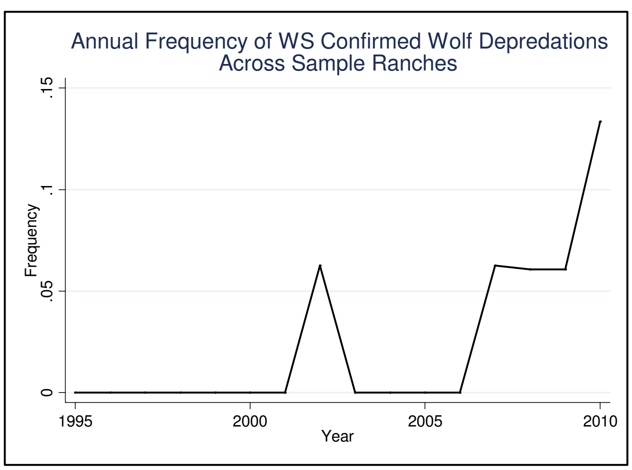

Figure 12

Though it appears that, on average, over time the frequency of WS confirmed wolf depredations on sample ranches is increasing (Figure 12) the total number of observations with a confirmed wolf depredations in the sample is very small.

Overall, only 10 (2.9%) of the 437 sample observations have at least one WS confirmed wolf depredation (Table 12) which is a very small percentage of all observations used in the analysis.

ANALYSIS

The ordinary least squares estimation model of sample yearly average calf weaning weight (**calf weight**) was conducted using Stata version 11. Because the original base estimation model did not produce residuals with homogeneous variance (Breusch-Pagan/Cook-Weisberg test for Heteroskedasticity: $\lambda^2 = 4.75$; $p \approx 0.029$) robust standard errors were used. Whether or not the calves were registered purebred (*registered*) is perfectly correlated with the ranch fixed effects in the estimation model and is therefore omitted from the model. Only two of the sample ranches registered their calves as purebred and did so every year of the study causing the perfect collinearity. The ranch fixed effects for the two respective ranches capture any variation in calf weight due to being registered purebred, among any other fixed effects.

The base OLS estimation model is a statistically significant predictor of average calf weaning weight (model $F = 59.32$; $p < 0.001$) and describes the variation in calf weight fairly well (R-squared = 0.846) (Table 13: model 1). Looking at the results presented in Table 13 of the base estimation model with no wolf presence variables (1), whether or not range riders were used on the sample ranch during the time calves were on summer pasture, artificial insemination was used as a form of impregnation of mother cows, and the approximate number of calves sold by the sample ranch were found to be insignificant ($p \approx 0.463$; $p \approx 0.862$; $p \approx 0.283$, respectively) factors on sample calf weight.

Sex of Calf—Relative to heifer calves, on average, steer average weaning weights are significantly (β=50.0; $p < 0.001$) heavier in the sample. On average, steer annual average weaning weights are 50 pounds heavier compared to that of female calves, holding all else constant. Though the magnitude of the weight difference between steers and heifers is slightly

TABLE 13: OLS estimation results

Variable	calf weight (1)	calf weight (2)	calf weight (3)	calf weight (4)	calf weight (5)	calf weight (6)	calf weight (7)	calf weight (8)
calf sex - steer	50.0***	50.0***	50.0***	50.0***	49.9***	50.0***	49.7***	49.6***
	(2.86)	(2.86)	(2.86)	(2.86)	(2.84)	(2.84)	(2.99)	(2.93)
calf age (days)	0.34*	0.34*	0.34*	0.34*	0.34*	0.34*	0.72***	0.74***
	(0.180)	(0.180)	(0.180)	(0.180)	(0.181)	(0.181)	(0.202)	(0.199)
hormone implanting (y/n)	24.5***	24.3***	24.3***	24.2***	24.8***	24.3***	8.2	9.2
	(5.89)	(5.92)	(5.93)	(5.92)	(5.98)	(6.00)	(7.75)	(8.16)
approximate # of calves sold	-0.06	-0.07	-0.07	-0.07	-0.07	-0.07	-0.06	-0.07
	(0.060)	(0.060)	(0.060)	(0.060)	(0.060)	(0.060)	(0.080)	(0.077)
artificial insemination (y/n)	1.6	1.7	1.6	1.8	2.5	2.7		
	(9.28)	(9.30)	(9.28)	(9.31)	(9.37)	(9.41)		
range riders (y/n)	14.3	12.0	11.9	12.5	15.1	10.8	3.3	6.4
	(19.45)	(19.68)	(19.76)	(19.53)	(19.17)	(19.50)	(15.59)	(15.25)
mean NDVI	-1.00	-1.00	-1.00	-1.03	-1.00	-1.00	-2.16**	-2.12**
	(0.970)	(0.980)	(0.981)	(0.975)	(0.968)	(0.985)	(0.993)	(0.975)
standard deviation of NDVI	1.67*	1.66*	1.64*	1.65*	1.63*	1.60	1.19	1.04
	(0.962)	(0.963)	(0.964)	(0.962)	(0.969)	(0.972)	(1.220)	(1.241)
annual average temperature (degrees F)	4.27*	4.30*	4.34*	4.30*	3.03	2.94	6.32**	2.77
	(2.305)	(2.305)	(2.309)	(2.301)	(2.431)	(2.446)	(3.030)	(3.835)
annual aggregate precipitation (inches)	2.16***	2.19***	2.20***	2.20***	2.20***	2.27***	1.30*	1.44*
	(0.564)	(0.565)	(0.570)	(0.567)	(0.555)	(0.554)	(0.755)	(0.745)
annual aggregate snowfall (inches)	-0.24***	-0.24***	-0.24***	-0.24***	-0.25***	-0.26***	-0.29***	-0.33***
	(0.074)	(0.073)	(0.074)	(0.074)	(0.073)	(0.072)	(0.084)	(0.083)
ranch overlaps MFWP wolf home range (y/n)								
all MCPs & centroids		2.5				4.9		
		(4.38)				(4.43)		
all MCPs; no centroids			2.7					
			(4.69)					
all MCPs; buffered centroids $^{\Omega}$				2.8				
				(3.94)				
Wildlife Service confirmed wolf depredation (y/n)					-20.4**	-22.8**		-22.0**
					(10.06)	(10.06)		(10.40)
calf breed (base case = black angus)	yes	yes	yes	yes	yes	yes	yes	yes
ranch fixed effects	yes	yes	yes	yes	yes	yes	yes	yes
year fixed effects	yes	yes	yes	yes	yes	yes	yes	yes
constant	388.1**	386.6**	384.3**	390.4**	445.0**	448.9**	379.1*	533.7*
	(172.7)	(173.7)	(174.4)	(173.1)	(176.1)	(177.2)	(211.3)	(243.0)
Observations	437	437	437	437	437	437	243	243
Total # of sample ranches	18	18	18	18	18	18	10	10
R-squared	0.846	0.846	.846	.846	0.848	0.848	8.53	8.56

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.10
$^{\Omega}$ centroid packs buffered to a total radius of 13.82 km (Rich, 2010)

higher, this result is consistent with others that suggest steers gain, on average 5% (Hanawalt, 2011) to 7% (Beffa, van Wyk & Erasmus, 2009) more weight than their female counterparts.

Age of Calf—The average age of the calves on sample ranches was found to have a fairly significant direct effect on calf weight with a coefficient equal to 0.34 pounds per day ($p \approx 0.057$) (Table 13: model 1). On average, an addition of approximately 3 days of age increases the average weaning weight of sample calves by 1 pound, holding all else constant. Though the magnitude of this result is lower, it is in line with others who have found that an increase in age can increase calf weaning weight by 1.20 (Minyard & Dinkel, 1965), 1.33 (Koger & Knox, 1945), and as much as 1.46 pounds per day (Botkin & Whatley, 1953). The difference in magnitude of the effect age has on weaning weight of calves found in this study compared to previous studies may be attributed to the precision of measurement of the actual age of the calves in the samples. This study's measurement calf age in the sample is an estimated age calculated based on approximate start and end dates of calving season on a particular ranch *i* in year *t*.

Hormone Implanting—The use of growth hormone implants in sample calves appears to have a very significant (β=24.5; $p < .001$) effect in boosting calf weight (Table 13: model 1). On average, sample ranches that used some sort of growth hormone implant produced calves that were 24.5 pounds heavier relative to ranches that opted not to use growth hormone implants (Table 13: model 1). This result is in line with previous studies concerned with the effects of growth hormones on calf weight gain, although, the magnitude of the effect is much smaller compared to most who have found as much as a 23% (Kahl, Bitman & Rumsey, 1978), 20% (Burroughs, et al., 1954) and similar increases in weight gain by calves due to growth hormones (Rumsey, et al., 1996; Dimius, et al., 1976; Embry & Gates, 1976; Rumsey & Oltjen, 1975).

Disparity in the magnitude of the effect growth hormones have on average daily weight gained by calves may be attributed to differences in timing of implanting during the growing stages of the calves as well as dosage amounts (Hunt, et al., 1991).

NDVI—On average, the measure of the average amount of forage available to cows during the year (*mean NDVI*) was not a statistically significant factor on calf weight ($p \approx .301$). However, the variable used as a measure of the length of the vegetative growing season (*standard deviation of NDVI*) was found to be fairly significant (β=1.67; $p \approx .083$) and to have a direct positive effect on the average weaning weight of calves (Table 13: model 1). This finding is consistent with research on wild ungulates such elk (Hebblewhite, Merrill & McDermid, 2008), juvenile big horn sheep (Pettorelli, Pelletier, Hardenberg, et al., 2007), red deer (Mysterud, Langvatn, Yoccoz, et al., 2002), and alpine reindeer (Pettorelli, Weladji, Holand, et al., 2005). On average, a one unit increase of the standard deviation of the total NDVI curve (explained in the Methods section above) increases calf weight by approximately 1.67 pounds. This is interpreted as, on average, sample calves raised on summer pasture with a longer vegetative growing season gain more weight than those raised in areas with shorter, more drastic growing seasons, holding all else constant.

Climate Variables—Climatological factors were found to have a fairly significant effect on calf weight (Table 13: model 1). An increase in the annual average temperature on a ranch was found to be fairly significant (β=4.27; $p \approx 0.065$) in boosting average calf weaning weights in the sample. On average, an increase in the annual average temperature on a sample ranch by one degree Fahrenheit effectively increases calf weight by 4.27 pounds, holding all else constant.

Annual aggregate precipitation was found to be a very significant (β=2.16; $p < 0.001$) contributing factor to average calf weaning weight. On average, the addition of an inch of annual precipitation on a sample ranch increases calf weight by 2.16 pounds, holding all else constant.

Although the magnitude of the effect is not very large, annual aggregate snowfall was also found to be a very significant (β=-.24; $p \approx 0.001$) factor of calf weight. On average, a 4 inch increase in the annual snowfall on a sample ranch effectively decreases average calf weaning weight by about one pound, holding all else constant.

Wolf Presence Variables—The three different variations of the MFWP wolf home range MCP and centroid data used to create the first discrete measure of wolf presence on a sample ranch (if a sample ranch overlaps at least one wolf home range MCP or centroid) produced very similar, non-significant results in the analysis (Table 13). No matter what variation of MFWP wolf home range data used (model 2: all MCPs and centroids ($p \approx .569$), model 3: all MCPs and no centroid pack home ranges ($p \approx 0.570$), or model 4: all MCPs and centroid packs buffered to a total radius equaling 13.82 kilometers ($p \approx 0.476$)), there is no significant difference in calf weight between ranches that were and were not spatially overlapped by at least one MFWP wolf home range MCP or centroid. Because all variations of wolf home range MCP and centroid data produced similar results, all original wolf home range MCPs and centroids are used in further analysis.

The robustness tests on the coefficient of the wolf presence variable based on MFWP wolf home range MCP and centroid data (*ranch overlaps MFWP wolf home range* —Table 13: model 2) bolster the results of the original estimation model of calf weight gain (Table 14:

TABLE 14: OLS estimation results – Comparison between variations of MFWP wolf home range data

Variable	calf weight (1)	calf weight (2)	calf weight (9)	calf weight (10)
calf sex - steer	50.0***	50.0***	50.0***	50.0***
	(2.86)	(2.86)	(2.86)	(2.85)
calf age (days)	0.34*	0.34*	0.34*	0.34*
	(0.180)	(0.180)	(0.179)	(0.179)
hormone implanting (y/n)	24.5***	24.3***	24.3***	24.5***
	(5.90)	(5.92)	(5.90)	(5.85)
approximate # of calves	-0.0643	-0.0651	-0.0654	-0.0684
	(0.0598)	(0.0599)	(0.0598)	(0.0600)
artificial insemination (y/n)	1.6	1.7	1.7	3.4
	(9.28)	(9.30)	(9.31)	(9.61)
range riders (y/n)	14.28	12.02	12.10	9.107
	(19.45)	(19.68)	(19.73)	(19.77)
mean NDVI	-1.00	-1.00	-1.00	-1.03
	(0.970)	(0.980)	(0.981)	(0.988)
standard deviation of NDVI	1.67*	1.66*	1.67*	1.66*
	(0.962)	(0.963)	(0.963)	(0.960)
annual average temperature (degrees F)	4.27*	4.30*	4.27*	4.34*
	(2.305)	(2.305)	(2.306)	(2.307)
annual aggregate precipitation (inches)	2.16***	2.19***	2.18***	2.14***
	(0.564)	(0.565)	(0.564)	(0.570)
annual aggregate snowfall (inches)	-0.24***	-0.24***	-0.24***	-0.24***
	(0.074)	(0.073)	(0.073)	(0.073)
ranch overlaps MFWP wolf home range (y/n)				
OL – all original MCPs and centroids		2.5		
		(4.38)		
OL1 – all MCPs and centroids buffered by 1 km			2.5	
			(4.35)	
OL5 – all MCPs and centroids buffered by 5 km				6.4
				(4.18)
calf breed (base case = black angus)	yes	yes	yes	yes
ranch fixed effects	yes	yes	yes	yes
year fixed effects	yes	yes	yes	yes
constant	388.1**	386.6**	386.8**	393.1**
	(172.7)	(173.7)	(173.6)	(173.7)
Observations	437	437	437	437
Total # of sample ranches	18	18	18	18
R-squared	0.846	0.846	0.846	0.847

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.10

models 9 & 10). When the latent variable OL is redefined to equal one if a sample ranch is located within one (OL1 = 1) or 5 kilometers (OL5 = 1) from a MFWP wolf home range MCP or centroid and zero otherwise, a similar, statistically insignificant effect of wolf presence on calf weight gain is found.

The second discrete measure of wolf presence on sample ranches produced interesting results. Whether or not a sample ranch had at least one United States Department of Agriculture: Wildlife Services (WS) confirmed wolf depredation was found to be a statistically significant factor on sample average weaning weight of calves (β = -20.4; p ≈ .044) (Table 13: model 5). This is interpreted as sample ranches that had at least one WS confirmed wolf depredation during a year produce calves that wean, on average, approximately 20 pounds lighter than sample ranches that do not experience any WS confirmed wolf depredations during the same year, holding all else constant.

A test for robustness of this finding shows similar estimation results (Table 13: models 7 & 8). The estimation model was run using only sample ranches that are assumed to be in areas that wolves use as home range habitat (Table 13: model 7 & 8). Eight of the sample ranches used in the analysis never had a MFWP wolf home range MCP or centroid spatially overlap the ranch over the time period of the study. It is assumed that these ranches are producing calves that rarely or never experience any interaction with wolves. When the estimation model is run using only sample ranches that are producing calves in areas assumed to have some wolf presence (sample ranches with at least one MCP or centroid overlap during the time period of the study) the effect of having a WS confirmed wolf depredation on the sample ranch is very similar in both magnitude and significance (β = -22.0; p ≈ 0.036) to the estimation results using all sample ranches (β = -20.4; p ≈ .044). This finding substantiates the original results and suggests there isn't any unobserved characteristic omitted from the estimation model of ranches in areas with wolf presence that is negatively correlated with calf weight gain.

Though it is not significant in either the robustness or the original estimation model, it should be noted that the use of artificial insemination as a means of impregnation of the mother cows is omitted from robustness estimation model due to perfect correlation with the ranch fixed effects (Table 13: model 7 & 8). Only one of the 10 sample ranches analyzed in the robustness estimation models (7) & (8) used artificial insemination and did so every year over the time period of the study causing the collinearity.

DISCUSSION

The measure of wolf presence on sample ranches based on MFWP wolf home range MCP data was not found to be a significant factor on sample calf average weaning weight (Table 13: model 2) in the estimation model. This implies that, based on the analyzed sample, the measure of wolf presence on ranches (OL) as defined, a measurable effect of wolf presence on average calf weight gain was not found. It is theorized that this finding suggests one or a combination of things.

One possible explanation is that the MFWP estimated annual wolf territory MCP and centroids are not precise enough or of a sufficient fine scale resolution to be used as a factor to assess potential effects of wolf presence on calf weight gain on sample summer grazing pastures. The relatively low level of monitoring intensity and frequency for an analysis of this type, as discussed previously, may explain the lack of statistical significance.

A second possible reason for the statistical insignificance of having a MFWP wolf home range MCP or centroid overlap a sample ranch on calf weight gain is cattle herds may feel unthreatened by wolf presence and maximize optimal foraging efficiency until a depredation on a member of the herd is experienced. Most Montana wolves regularly encounter livestock without posing any direct depredation threat to the herd (Sime, Bangs, Bradley, et al. 2007). This theory is substantiated by the presented estimation results (Table 13) on the effect of having a WS confirmed wolf depredation on a sample ranch's average calf weaning weight. It is suggested that when cow-calf pairs witness and are potentially harassed by the threat of direct wolf depredation they feel wolves pose a threat and therefore are affected through decreased calf weight gain.

The decrease in calf weight gain from having at least one WS confirmed wolf depredation on the sample ranch could be attributed to a variety of things culminating from increased wolf presence but the estimation model does not allow for causal inference. When cattle experience a confirmed wolf depredation, they may opt to change their movement patterns to alleviate interaction with wolves. If cows are spending more time in areas with sub-optimal foraging availability and being vigilant, they are decreasing the amount of forage intake, expending more of the vegetative resource to energy for movement and thus are not gaining weight at an optimal rate. This along with direct harassment of the herd from wolves which increases stress levels may be factors in why calves are gaining sub-optimal weight, but these are speculations and cannot be tested under the estimation design of this study.

Another possible explanation for the results is that even if wolf presence using wolf MCP and centroid data as a metric for wolf presence is statistically insignificant, GIS analysis confirms there is some overlap between wolf territories and sample summer pastures on the landscape. By the time a Wildlife Service agent confirms a livestock death due to wolves, interactions between wolves and the cattle have likely been occurring for an unknown period of time. Prior to a WS confirmed wolf depredation during a given year, wolves may have likely been chasing and harassing the herd. These interactions between wolves and the cow-calf herd prior to a WS confirmed wolf depredation may affect the herd's foraging efficiency, vigilance levels, and stress levels which could correlate to suboptimal forage intake and energy expenditure leading to decreased calf weight gain.

The spatial distribution of the WS confirmed wolf depredations that occurred on sample ranches over the time period of the study is represented in Figure 13. All of the WS confirmed wolf depredations that occurred on sample ranches were in the southwestern part of Montana. This, along with the low number of instances of WS confirmed wolf depredations on sample ranches (N = 10) suggests that the presented estimation results be interpreted with caution. The generality of the presented results to the entirety of western Montana may not be applicable given the segregation of observed WS confirmed wolf depredations to two counties (Madison & Park) in the southern region of the state.

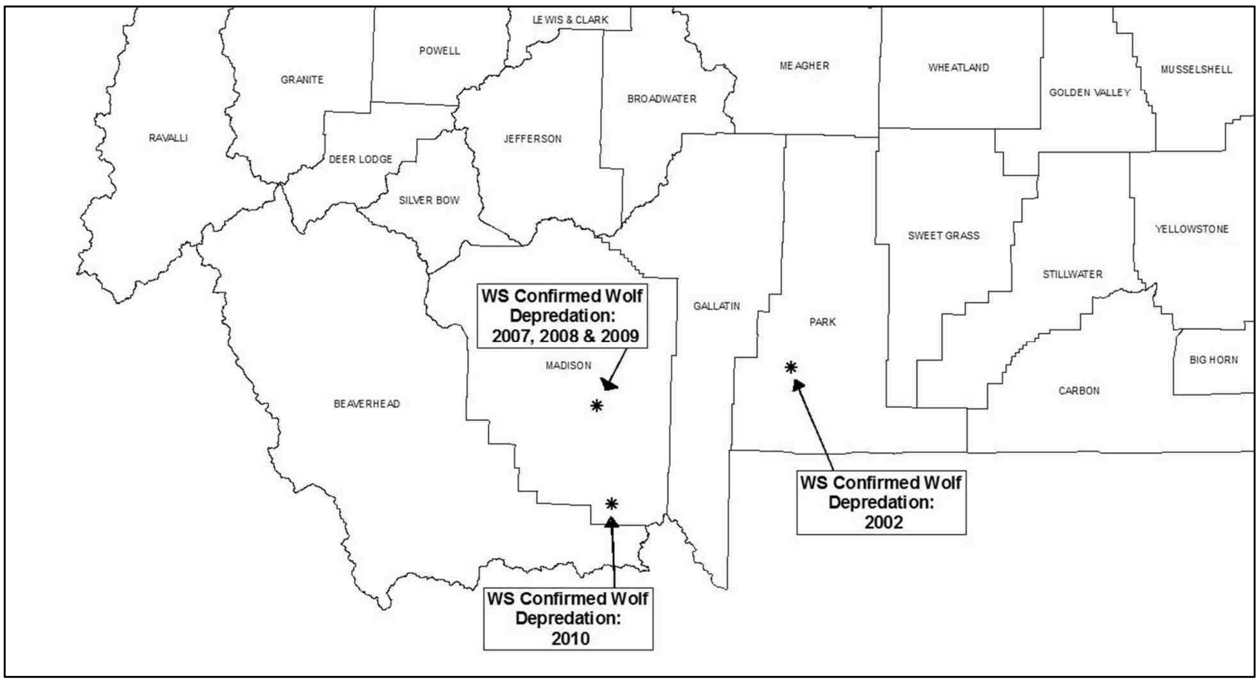

Figure 13

Table 15 shows a comparison of the summary statistics of the independent variables used in the estimation model between ranches in years that did and did not have at least one WS confirmed wolf depredation. Sample calf weaning weight on ranches in years that had at least one WS confirmed wolf depredation are, on average, lighter (mean = 610.0 pounds: SD = 38.96) than ranches in years that didn't experience a WS confirmed depredation (mean = 626.8 pounds; SD = 65.05). On ranches in years with at least one WS confirmed wolf depredation, on

Table 15: Summary statistics of sample ranches with and without at least one Wildlife Service confirmed wolf depredation

	Ranch-Year Observations *Without* at least one WS Confirmed Wolf Depredation					Ranch-Year Observations *With* at least one WS Confirmed Wolf Depredation				
Variable	**# Obs.**	**Mean**	**Std. Dev.**	**Minimum**	**Maximum**	**# Obs.**	**Mean**	**Std. Dev.**	**Minimum**	**Maximum**
Average Calf Weight (pounds)	427	626.8	65.05	461	809	10	610.0	38.96	557	673
Steers	221	651.4	60.78	478	809	5	629.4	36.96	594	673
Heifers	206	600.4	58.94	461	749	5	590.6	33.29	557	639
Average Age of Calves (days)	427	239.9	33.58	160	347	10	258.2	16.73	240	278
Hormone Implanting (y/n)	427	0.34	0.474	0	1	10	0.5	0.53	0	1
Approximate # of Calves Sold	427	249.5	234	65	1300	10	871.4	553.65	200	1300
Artificial Insemination (y/n)	427	0.09	0.282	0	1	10	0	0	0	0
Range Riders (y/n)	427	0.08	0.271	0	1	10	0	0	0	0
Annual Average Temperature (degrees F)	427	43.5	3.03	35.3	49.3	10	41.5	2.89	36.3	44.1
Annual Aggregate Precipitation (inches)	427	16.2	5.54	6.0	33.1	10	17.4	7.05	12.1	30.4
Annual Aggregate Snowfall (inches)	427	65.1	50.16	0	263.5	10	67.7	20.27	37.5	98.3
Mean NDVI	427	140.05	6.626	125.17	163.49	10	135.20	5.789	129.76	145.73
Standard Deviation of NDVI	427	14.50	3.082	7.48	22.07	10	13.87	2.780	11.28	17.90
Ranch Size (acres)	427	13641.4	19342.92	2000	64000	10	39600.0	19884.11	2000	50000
Ranch Elevation (feet)	427	1612.40	298.287	1154.93	2188.59	10	1850.40	185.605	1670.77	2188.59
Ranch Slope (degrees)	427	8.57	4.483	1.82	20.41	10	9.21	1.415	8.41	11.86

average, the approximate number of calves sold (mean = 871; SD 553.65) and the ranch size (39,600 acres; SD = 19,884.11) is noticeably larger compared to sample ranches in years that didn't experience a confirmed wolf depredation; although, the range in variation of the respective variables in both ranch types is very large. The climatological and NDVI variable averages are fairly similar between ranches in years that did and did not experience at least one WS confirmed wolf depredation.

The majority of western Montana calf producers sell their calf herd as feeder cattle at a by-the-pound price. A herd of calves that is, on average, lighter than expected directly correlates to lower economic revenue received by the producer. Following the presented estimation results, a western Montana cow-calf producer selling 260 calves (the approximate average number of calves sold by ranches in the observed sample) weighing 626 pounds (the average weight of observed calf weight in the sample) at the average selling price of steers and heifers in Montana in November of 2010 of $1.15 per pound (United States Department of Agriculture, 2010), they would expect to get $187,174. If, however, that producer experienced a Wildlife Service confirmed wolf depredation on their cattle herd during the year of 2010, on average, when the calves were sold they would weigh approximately 20 pounds lighter than if there hadn't been a WS confirmed wolf depredation on the ranch during the year. The decrease in weight gained by the calf herd would subsequently result in revenue from the calf sale equal to $181,194. This is a 3.19% marginal loss in revenue (equal to $5,980) taken by the producer due to having at least one WS confirmed death loss due to wolves during the year calves were on summer pasture. Plus or minus one standard deviation, the estimated economic effect could range from as much as $8,970 and as little as $2,990.

The effect of having at least one WS confirmed wolf depredation on the ranch on calf weight gain is comparable to using a hormone implant on the sample calves. Sample ranches that used hormone implants on their calves, on average, had calves that were 24.3 pounds (SD = 6.00) heavier compared to ranches that opted not to used hormones, holding all else constant. Though the net effect of having a WS confirmed wolf depredation on sample calf weight gain may be offset by the use of hormone implanting. The added cost of hormones, time spent administering, and consumer demand for hormone-free beef then comes into question.

In 2010, Wildlife Services confirmed that 87 cattle in Montana were killed by wolf depredation (Sime, Asher, Bradley, et al., 2011). The aggregate effect of WS confirmed wolf depredations on average calf weight gain across western Montana cattle ranches is dependent on the number of ranches that experienced more than one confirmed wolf depredation in a particular year. Keep in mind the measure of wolf presence used in the analysis is defined to equal one if a sample ranch experienced *at least one* WS confirmed wolf depredation throughout the year. Assuming all 87 cases of WS confirmed wolf depredation on cattle occurred on different ranches in Montana in 2010 and each ranch sold 260 calves at $1.15 per pound, the highest estimated aggregate effect on western Montana cattle production may be as high as $520,260. If, however, 40 of the 87 cases of WS confirmed wolf depredation occurred on different ranches, the estimated aggregate effect may be closer to $239,200. In 2009, the Montana Livestock Loss Reduction & Mitigation Board (LLRMG) paid almost $145,000 to Montana ranchers for *all* livestock (not just cattle) lost due to wolf predation (Sime, Asher, Bradley, et al., 2011) and over $98,000 in 2010 (Edwards, 2010). The indirect costs of wolf predation on cow-calf ranches, such as decreased calf weight gain, may potentially be 2 to 5 times greater than what the LLRMB is currently paying for all livestock lost to wolf predation. These back of the envelope calculations are purely speculative and highly dependent on the actual number of calves sold by each affected producer, the price at which the calves are sold, and the actual number of ranches that are affected by at least one WS confirmed wolf depredation.

The findings of this study suggest that a program set up to compensate ranchers for lost calf weight gain due to having at least one WS confirmed wolf depredation on the ranch could be implemented; though, it would be at a substantial cost relative to the current wolf depredation compensation funding level. As the results suggest, the observed average producer who experiences at least one WS confirmed wolf depredation weans calves that are 20 pounds lighter than if there hadn't been a confirmed wolf depredation on the place. A suggested economic compensation program would pay ranchers who have experienced at least one WS wolf depredation for lost revenue due to decreased weight gain by their calves. The program would pay the affected producer based on the number of calves sold and the price at which the calves were sold. For example, if a producer sold 200 calves at $1.15 per pound, the compensation program would pay the producer $4,600 dollars (200 calves * $1.15 * 20 pounds lost per calf due to WS confirmed wolf depredation) if the ranch experienced at least one WS confirmed wolf depredation during the respective year. The Montana Livestock Reduction & Mitigation Board is already established as a means of economic compensation to ranchers for livestock confirmed by Wildlife Services to have been killed by wolves in the state and could serve as a successful platform to implement such a compensation program.

CONCLUSION

Through ordinary least square regression analysis of a sample of western Montana cow-calf producers, it was found that a number of factors were significant in explaining variation in annual average calf weaning weights. Climate was found to be the most influencing factor on calf weight gain along with ranch specific husbandry practices such as the use of hormone implanting and calf age and the length of the vegetative growing season (Table 16). Having at least one Wildlife Service wolf depredation in a year on a sample ranch was also found to have a significantly negative effect on calf weight gain though its influence relative to the other covariates was smaller.

With the presented results suggesting the potential effect of having a Wildlife Service wolf depredation can have on average calf weaning weight beyond direct depredation, more research needs to be done on the issue. It is suggested that a study using a similar research design and estimation model be conducted with a larger and more expansive sample of western Montana cow-calf producers than the one used in this study. Also, further research should focus on potential differences in the effect of having one WS confirmed wolf depredation versus having more than one confirmed kill on calf weight gain. The potential difference in the effect of having multiple WS confirmed wolf depredations is beyond the scope of the current study. To my knowledge, no scientific research similar to this study has been conducted on the effect wolf presence along with other climatological, environmental, and rancher husbandry factors has on calf weaning weight in any other cattle ranching area such as Wyoming, Idaho, and other agricultural areas with similar wolf populations. Research in these other areas could contribute to a broader understanding of the dynamic interaction between the cow-calf production industry and wolves.

WORKS CITED

Agriculture & Business. (2007). Retrieved February 16, 2011, from MontanaKids.com: Official Montana Website: http://montanakids.com/agriculture_and_business/farm_animals/Cattle.htm

Alderman, J. H. (2006, August 13). Scared skinny: Ranchers say fear of wolves causing livestock to lose weight. *Missoulian*.

Alderton, B. W., Hixon, D. L., Hess, B. W., Woodard, L. F., Hallford, D. M., & 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., & 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., & Brown, J. S. (2001). Assessing effects of predation risk on foraging behavior of mule deer. *Journal of Mammalogy, 82*(2), 430-439.

Animal & Veterinary: NADA 141-043 Synovex Plus - origional approval. (2009, October 28). Retrieved June 29, 2011, from U.S. Department of Health & Human Services: FDA: http://www.fda.gov/AnimalVeterinary/Products/ApprovedAnimalDrugProducts/FOIADrugSummaries/ucm116149.htm

Arnold, J. W., Bertrand, J. K., Benyshek, L. L., Comerford, J. W., & Kiser, T. E. (1990). Selection for low birth weight and high yearling weight in angus beef cattle. *Livestock Production Science, 25*(1-2), 31-41.

Azzam, S. M., Kinder, J. E., Nielsen, M. K., Werth, L. A., Gregory, K. E., Cundiff, L. V., et al. (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). Retrieved March 17, 2011, from Defenders of Wildlife: http://www.defenders.org/programs_and_policy/wildlife_conservation/solutions/wolf_compensation_trust/background.php

Bangs, E. E., & Fritts, S. H. (1996). Reintroducting the gray wolf to central Idaho and Yellowstone National Park. *Wildlife Society Bulletin, 24*(3), 402-413.

Barlow, R., Belinda Dettmann, E., & 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., & Ritter, R. (1994). Vigilance in Nxai Pan springbok, Antidorcas marsupialis. *Behaviour, 129*(1), 1-11.

Beffa, L. M., van Wyk, J. B., & 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.

Botkin, M. P., & 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. & White, C. C. (1995). Dispersal characteristics of a colonizing wolf population in the Rocky Mountains. In Carbyn, L. N., Fritts, S. H. & Seip D. R. eds., *Ecology and conservation of wolves in a* *changing world* (pp. 135-140). University of Alberta, Edmonton: Canadian Circumpolar Inst.

Bradley, E. H., & 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., et al. (2005). Evaluating wolf translocation as a nonlethal method to reduce livestock conflicts in the northwestern United States. *Conservation Biology*, 1498-1508.

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

Brown, C. J. (1960). Influence of year and season of birth, sex, sire, and age of dam on weights of beef calves at 60, 120, 180, and 240 days of age. *Journal of Animal Science, 19*, 1062-1070.

Brown, J. E., Brown, C. J., & 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., & 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., & Wirtz II, W. O. (1988). The effects of owl predation on the foraging behavior of heteromyid rodents. *Oecologia, 76*(3), 408-415.

Bureau of Land Management. (2010, December 2). Retrieved February 16, 2011, from Grazing: http://www.blm.gov/wo/st/en/prog/grazing.html

Burgess, J. B., Landblom, N. L., & 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., Kastelic, J., Cheng, E. W., & Hale, W. H. (1954). Oral administration of diethylstilbestrol for growth and fattening in beef cattle. *Journal of Animal Science, 13*, 978.

Cattle breeds: Friesian. (n.d.). Retrieved March 24, 2011, from The Cattle Site: http://www.thecattlesite.com/breeds/dairy/24/friesian

Cooperative Observer Program Fact Sheet. (2010, July). Retrieved Month 31, 2011, from National Oceanic and Atmospheric Administration: http://www.nws.noaa.gov/om/coop/Publications/coop_factsheet.pdf

Cundiff, L. V., Willham, R. L., & 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., & 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., & 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.

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

Dietz, R. E., Hall, J. B., Whittier, W. D., Elvinger, F., & 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., & 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., & 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.

Edwards, G. (2010). *2010 draft report.* Helena, Montana: Montana Livestock Loss Reduction & Mitigation Program.

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

Embry, I. B., & 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., & 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.

Frequently Asked Questions about the Wolf Compensation Trust. (2011). Retrieved March 17, 2011, from Defenders of Wildlife: http://www.defenders.org/programs_and_policy/wildlife_conservation/solutions/wolf_compensation_trust/frequently_asked_questions.php

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

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

Hanawalt, K. (2011). *Cutting Pairs.* Retrieved February 16, 2011, from Montana Cowboy College: http://www.montanacowboycollege.com/cutting_pairs.htm

Harper, E. K., Paul, W. J., & 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., & 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. & McDermid, G. (2008). A multi-scale test of the forage maturation hypothesis in a partially migratory ungulate population. *Ecological Monographs*, 78, 141-166.

Heinemann, W. W., & 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., & Entwistle, K. W. (1989). Fertility in a tropical beef herd divergently selected for pregnancy rate. *Animal Production, 49*, 73-81.

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

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

Hunt, D. W., Henricks, D. M., Skelley, G. C., & 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., & Skinner, J. D. (1998). Vigilance behaviour in African ungulates: the role of predation pressure. *Behaviour, 135*(2), 195-211.

Kahl, S., Bitman, J., & 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., & 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., & 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.

Kie, J. G., Baldwin, J. A., & 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., & Bergman, D. L. (2008). Vigilance in cattle: the influence of predation, social interactions, and environmental factors. *Rangeland Ecology & Management, 61*(3), 321-328.

Koch, R. M., & Clark, R. T. (1955). Influence of sex, season of birth and age of dam on economic traits in range beef cattle. *Journal of Animal Science, 14*, 386-397.

Koger, M., & 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., & 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., & Hasson, O. (1991). Factors affecting gerbil foraging behavior and rates of owl predation. *Ecology, 72*(6), 2249-2260.

Kotler, B. P., Gross, J. E., & 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.

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

Laster, D. B., Glimp, H. A., & Gregory, K. E. (1972). Age and weight at puberty and conception in different breeds and breed-crosses of beef heifers. *Journal of Animal Science, 34*, 1031-1036.

Laundre, J. W., Hernandez, L., & 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 anti-predatory vigilance: the group-size effect. *Animal Behaviour, 49*, 11-20.

Livestock loss reduction and mitigation board -- purpose, membership, and qualifications. (2007). Retrieved March 22, 2011, from Montana Code Annotated 2009: http://data.opi.mt.gov/bills/mca/2/15/2-15-3110.htm

MacArthur, R. H., & Pianka, E. R. (1966). On optimal use of a patchy environment. *The American Naturalist, 100*, 603-609.

MacGregor, R. G., & 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., & 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., & 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. (1996). A new era for carnivore conservation. *Wildlife Society Bulletin, 24*(3), 397-401.

Mech, L.D. (1970). The wolf: the ecology and behavior of an endangered species. National Hisory Press, Garden City, N.Y. 384pp.

Minyard, J. A., & 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 Livestock Loss Reduction & Mitigation Board. (n.d.). Retrieved February 16, 2011, from Montana's Official State Website: Department of Livestock: http://liv.mt.gov/liv/LLRMB/usdacontact.asp

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

Montana State University Extension. (n.d.). Retrieved May 9, 2011, from About MSU Extension: http://www.msuextension.org/category.cfm?Cid=7

Muhly, T. B., & Musiani, M. (2009). Livestock depredation by wolves and the ranching economy in the Northwestern U.S. *Ecological Economics*.

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.

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

Nelms, G. E., & 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., & 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.

PLM - Patuxent Landscape Model. (n.d.). Retrieved June 27, 2011, from The University of Vermont : http://www.uvm.edu/giee/PLM/

Pettorelli, N., Pelletier, F., von Hardenberg, A., Festa-Bianchet, M. & 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. & 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. & 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., & Barrett, R. N. (2001). *Post-cowboy economics: Pay and prosperity in the new American west.* Washington D.C.: Island Press.

Radunz, A. E., Fluharty, F. L., Day, M. L., Zerby, H. N., & 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., Blakesley, A. J. (1989). First wolf den in western U.S. recent history. *Northwestern Naturalist*, 70, 39-40.

Ream, R. R., Fairchild, M. W., Boyd, D. K. & Smith, J. (1991). Population dynamics and home range changes in a colonizing wolf population. In Keither, R. B. & Boyce, M. S. eds. *The Greater Yellowstone Ecosystem: redefining America's wilderness heritage* (pp. 349-366). New Haven, Connecticut: Yale University Press.

Remote Sensing Phenology: NDVI from AVHRR. (2011, January 6). Retrieved May 2, 2011, from U.S. Department of the Interior: U.S. Geological Survey: http://phenology.cr.usgs.gov/ndvi_avhrr.php

Remote Sensing Phenology: NDVI the foundation for Remote Sensing Phenology. (2011, January 6). Retrieved May 2, 2011, from U.S. Department of the Interior: U.S. Geological Survey: http://phenology.cr.usgs.gov/ndvi_foundation.php

Rich, L. N. (2010). An assessment of territory size and the use of hunter surveys for monitoring wolves in Montana. 80.

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

Rollins, W. C., & Guilbert, H. R. (1954). Factors affecting growth of beef calves during the suckling period. *Journal of Animal Science, 13*, 517-527.

Rumsey, T. S., & 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., & 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., & Oloufa, M. M. (1948). Weaning weight of calves as related to age of dam, sex and color. *Journal of Animal Science, 7*, 514.

Sih, A. (1980). Optimal behavior: can foragers balance two conflicting demands? *Science, 210*, 1041-1043.

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 & Parks.

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

Skrypzeck, H., Schoeman, S. J., Jordaan, G. F., & 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., & 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., & 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.

Stuth, J. W. (1991). Foraging behavior. In R. K. Heitschmidt, & J. W. Stuth, *Grazing Management: An Ecological Perspective* (pp. 65-83). Portland, Oregon: Timber Press.

Swiger, L. A., Koch, R. M., Gegory, K. E., Arthaud, V. H., Rowden, W. W., & 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. P., Brownlee, J. W., & 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. & 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., & 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., & 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., & Wydeven, A. P. (2002). Wolf depredation on domestic animals in Wisconsin, 1976-2000. *Wildlife Society Bulletin, 30*(1), 231-241.

United States Department of Agriculture. (2010). *Agricultural Prices.* National Agricultural Statistics Service.

United States Fish & Wildlife Service. (1987). *Northern rocky mountain wolf recovery plan.* Denver, Colorado: U.S. Fish and Wildlife Service.

United States Fish & Wildlife Service. (1994). *The reintroduction of gray wolves to Yellowstone National Park and central Idaho: final environmental impact statement.* Helena, MT: U.S. Fish and Wildlife Service.

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

Wolf Compensation Payment Statistics. (n.d.). Retrieved March 22, 2011, from Defenders of Wildlife: http://www.defenders.org/resources/publications/programs_and_policy/wildlife_conservation/solutions/statistics_on_payments_from_the_defenders_wildlife_foundation_wolf_compensation_trust.pdf

Young, S. P., & Goldman, E. A. (1944). *The wolves of North America.* Washington, D.C.: The American Wildlife Institute.

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

Zehnder, C., & DiCostanzo, A. (n.d.). Alternative marketing options for your calf crop. *Preparing for Value Based Marketing Course*. University of Minnesota.

APPENDIX

FIGURE 1:
EMAIL SENT TO MONTANA CATTLEMEN'S ASSOCIATION MEMBERS

Dear Montana Cattle Rancher,

With the help of the Montana Cattleman's Association, you have been randomly selected to participate in a study being conducted by researchers at the University of Montana that will attempt to quantify possible indirect effects of wolf presence on weight gained by calves in Western Montana. With growing populations of wolves in Montana this study is a novel and unique attempt to quantify possible effects of wolves on cattle beyond the simple effects of predation.

The study will be conducted by Dr. Derek Kellenberg, Assistant Professor of Economics, Dr. Mark Hebblewhite, Assistant Professor of Wildlife Biology, and Joe Ramler, Master's student in Economics, at the University of Montana.

Cattleman's Association members across western Montana are being randomly selected to participate in the study. Participation will consist of a short phone conversation with Joe Ramler followed by a 45 minute to one hour personal interview to take place early summer 2010 at the individual's ranch (exact time and date of the interview will be set up during the phone conversation). To qualify for participation in the study, ranchers must meet the following two initial criteria:

1. pasture 80 pairs of cattle or more per year from 1995 to 2009; and

2. be willing to provide average annual weaning weights of calves from approximately 1995 to 2009.

We want to stress that ***all ranch specific information collected will be kept strictly confidential*** and will only be observed by the researchers on the project. If you meet the two above criteria and are willing to participate in this study, please click on the web address below where you will be directed to a University of Montana website. There you will be asked to provide your basic contact information for the purposes of setting up the phone and on-site surveys.

www.umt.edu/mcrw

Once you provide your contact information, we will contact you via telephone within the next several weeks. Thank you in advance for your time and participation in this important study.

Sincerely,

Joe Ramler

FIGURE 2:

SNAPSHOT OF THE WEBSITE USED TO ALLOW WESTERN MONTANA RANCHERS TO CONTACT US FOR POTENTIAL PARTICIPATION IN THE STUDY (WWW.UMT.EDU/MCRW/)

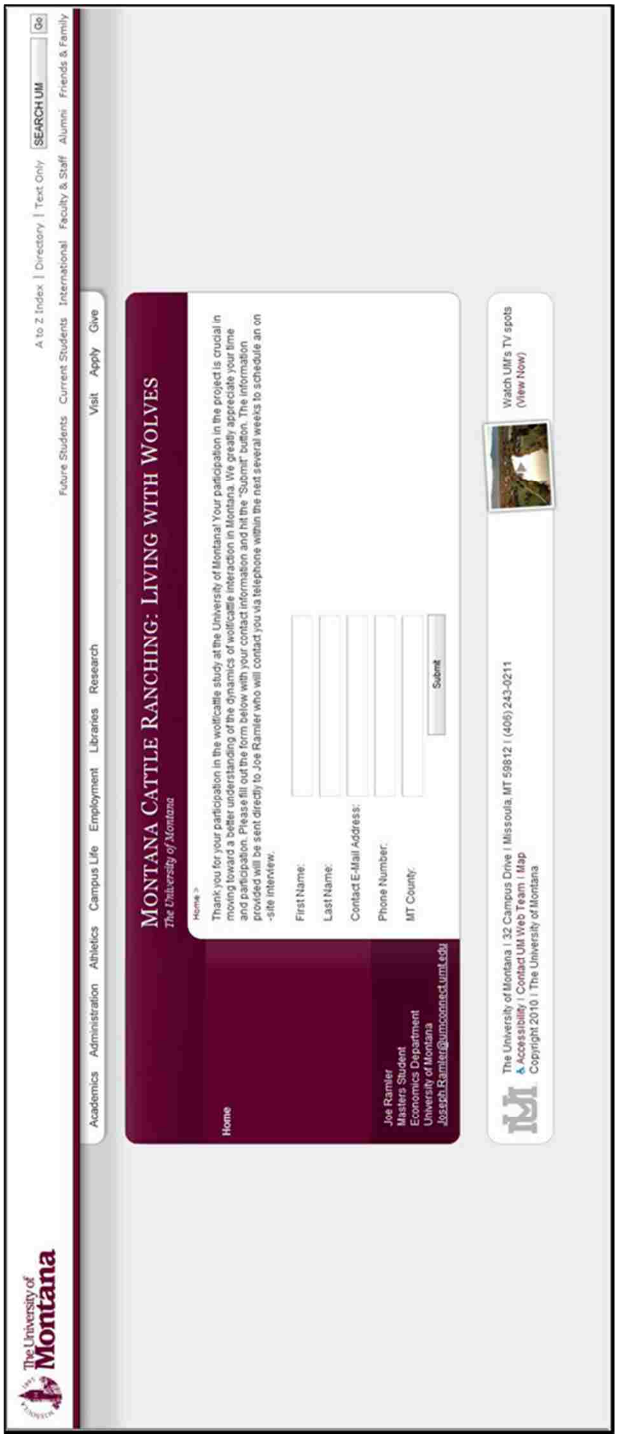

FIGURE 3:
MAP OF THE MONTANA CATTLEMEN'S ASSOCIATION (MCA) DISTRICTS

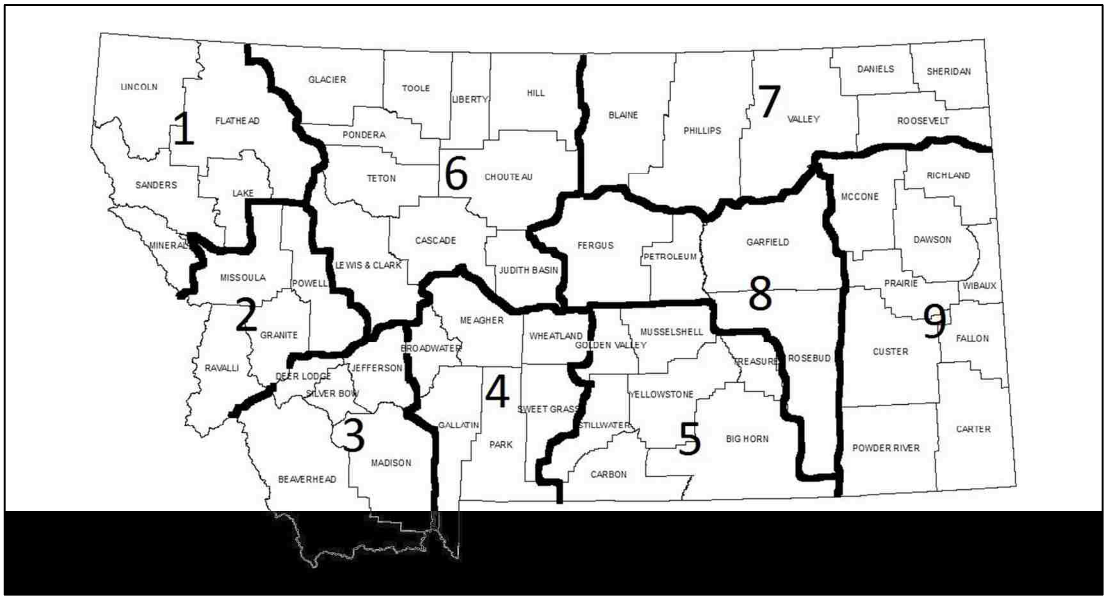

FIGURE 4:
MAP OF THE MONTANA STOCKGROWERS ASSOCIATION (MSA) DISTRICTS

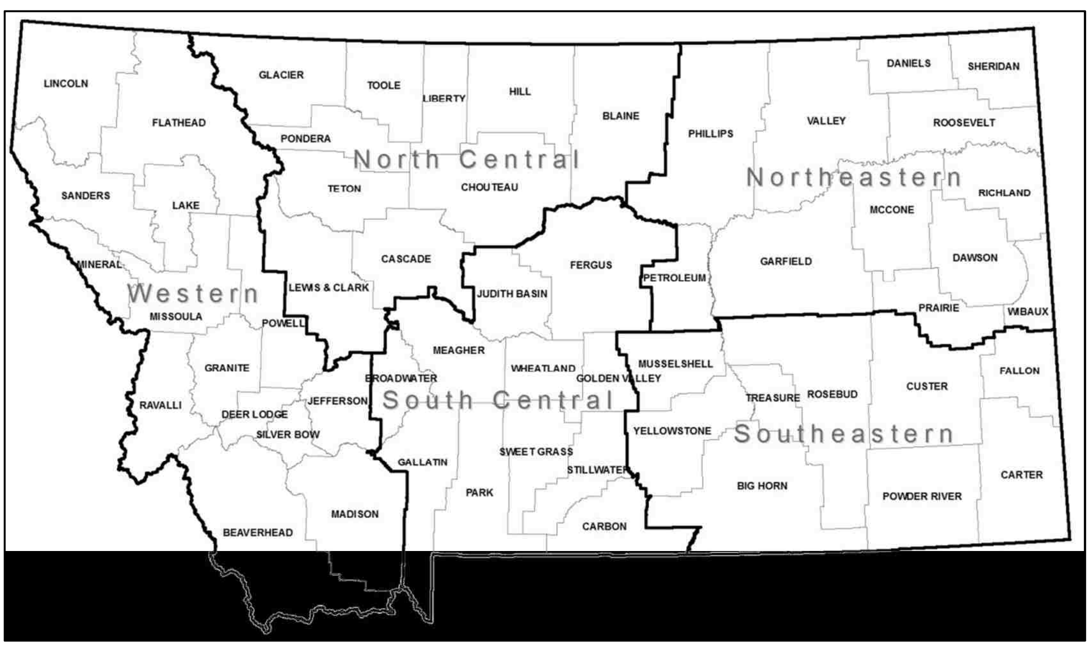

FIGURE 5:

LETTER MAILED TO PRODUCERS EXPLAINING THE STUDY AND ASKING FOR THEIR PARTICIPATION

Dear Montana Cattle Producer,

With the help of ***[insert agricultural organization]***, you have been selected to participate in a study being conducted by researchers at the University of Montana that will attempt to quantify possible indirect effects of wolf presence on weight gained by calves in Western Montana. With growing populations of wolves in Montana this study is a novel and unique attempt to quantify possible effects of wolves on cattle beyond the simple effects of predation.

The study will be conducted by Dr. Derek Kellenberg, Assistant Professor of Economics, Dr. Mark Hebblewhite, Assistant Professor of Wildlife Biology, and Joe Ramler, Master's student in Economics, at the University of Montana.

Cattle ranchers across western and central Montana are being asked to participate in the study. Participation will consist of a short phone conversation with Joe Ramler followed by a 30-45 minute personal interview to take place at the individual's ranch (exact time and date of the interview will be set up during the phone conversation). To qualify for participation in the study, producers must meet the following two initial criteria:

1. pasture 80 pairs of cattle or more per year from 1995 to 2009; and

2. be willing to provide average annual weaning weights of calves from approximately 1995 to 2009.

We want to stress that ***all ranch specific information collected will be kept strictly confidential*** and will only be observed by the researchers on the project. If you meet the two above criteria and are willing to participate in this study, please fill out the contact information card provided and mail it to Derek Kellenberg using the self addressed stamped envelope.

Once we get your contact information, we will contact you via telephone within the next few weeks. Thank you in advance for your time and participation in this important study.

Sincerely,

Joe Ramler

FIGURE 6:
INFORMATION CARD SENT TO WESTERN MONTANA CATTLE PRODUCERS WITH THE ABOVE LETTER (FIGURE 5) EXPLAINING THE STUDY AND ASKING FOR PARTICIPATION

Yes, I am willing to participate in the University of Montana wolf/cattle project by taking part in a short on-ranch survey. My contact information is below.
First Name:
Last Name:
E-Mail Address:
Phone Number:
MT County:

FIGURE 7:
MAP OF THE SUMMER PASTURE USED BY WESTERN MONTANA RANCHES IN THE OBSERVED SAMPLE

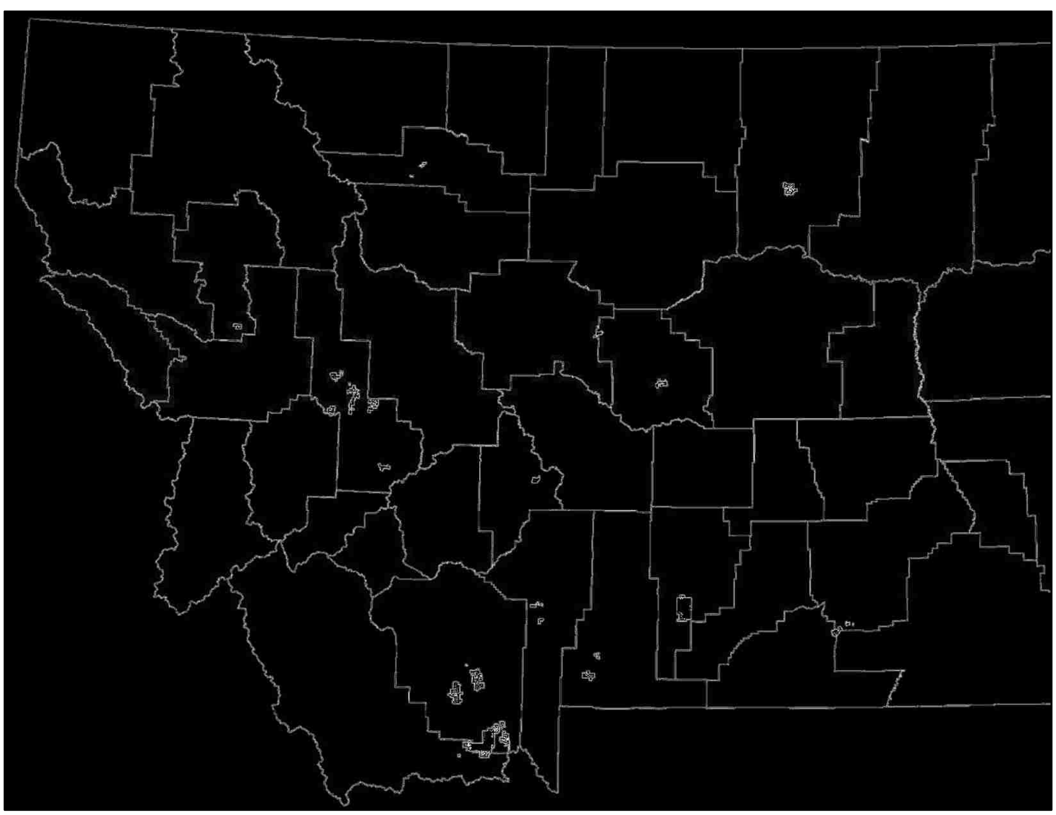

FIGURE 8:

MONTANA COUNTY CADASTRAL DATABASE: DATE AND TIME OF LAST UPDATE FOR THE DATA USED IN THE ANALYSIS (FTP://FTP.GIS.MT.GOV/CADASTRALFRAMEWORK/)

MONTANA COUNTY COMPRESSED CADASTRAL FILE	DATE & TIME OF DATA UPDATE
BEAVERHEAD.ZIP	9/13/2010 @ 4:46 PM
MADISON.ZIP	9/14/2010 @ 5:17 PM
GALLATIN.ZIP	9/14/2010 @ 10:17 AM
PARK.ZIP	10/05/2010 @ 4:08 PM
SWEETGRASS.ZIP	8/03/2010 @ 10:32 AM
STILLWATER.ZIP	8/03/2010 @ 10:32 AM
CARBON.ZIP	8/31/2010 @ 4:42 PM
RAVALLI.ZIP	8/03/2010 @ 10:22 AM
GRANITE.ZIP	9/14/2010 @ 10:13 AM
DEERLODGE.ZIP	8/31/2010 @ 9:15 PM
SILVERBOW.ZIP	8/03/2010 @ 10:24 AM
POWELL.ZIP	9/14/2010 @ 10:16 AM
JEFFERSON.ZIP	9/14/2010 @ 12:28 PM
BROADWATER.ZIP	8/31/2010 @ 9:14 PM
MEAGHER.ZIP	9/15/2010 @ 8:24 AM
JUDITHBASIN.ZIP	9/14/2010 @ 10:14 AM
CASCADE.ZIP	9/14/2010 @ 10:20 AM
LEWISCLARK.ZIP	8/31/2010 @ 4:47 PM
TETON.ZIP	8/03/2010 @ 10:33 AM
PONDERA.ZIP	9/15/2010 @ 9:33 AM
BLAINE.ZIP	6/30/2010 @ 8:52 PM
CHOUTEAU.ZIP	6/30/2010 @ 8:57 PM
HILL.ZIP	8/03/2010 @ 10:11 AM
LIBERTY.ZIP	9/14/2010 @ 10:15 AM
TOOLE.ZIP	9/15/2010 @ 8:36 AM
BIGHORN.ZIP	12/01/2010 @ 2:21 PM
YELLOWSTONE.ZIP	1/10/2011 @ 3:48 PM
LAKE.ZIP	12/15/2010 @ 8:34 PM
MISSOULA.ZIP	12/07/2010 @ 11:49 AM

FIGURE 9:

MAP OF ALL MONTANA COOPERATIVE OBSERVER PROGRAM (COOP) WEATHER STATIONS IN MONTANA

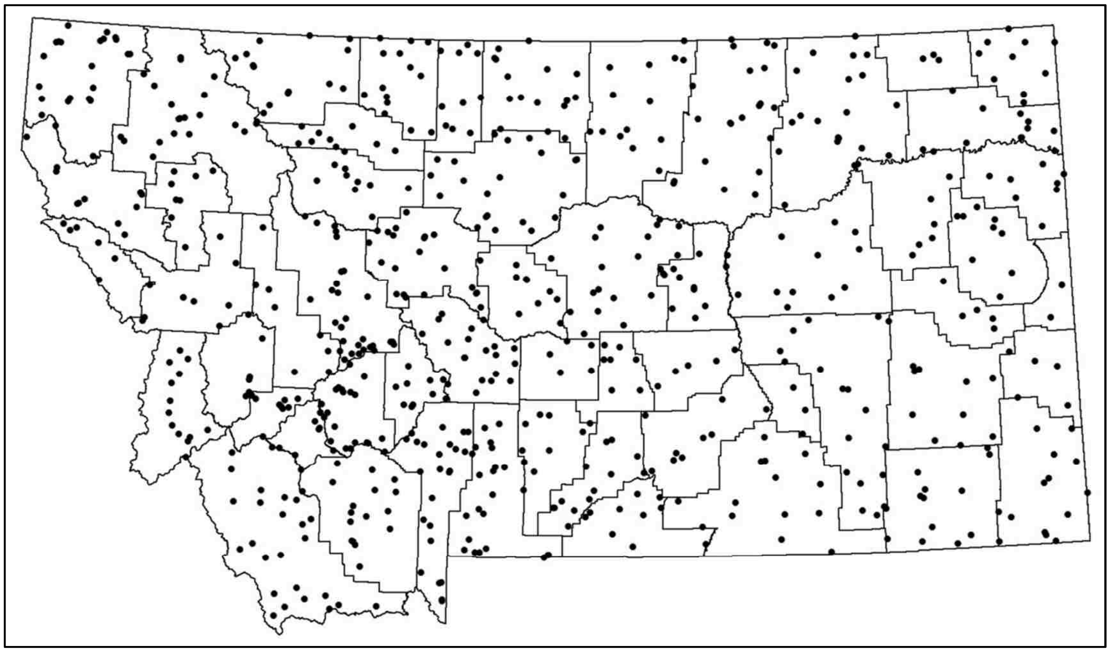

FIGURE 10:

THE SIMILAR TIME PERIODS (DISPLAYED BELOW) DURING EACH YEAR *T* WERE USED TO ESTIMATE THE INTEGRATED NDVI (*TOTAL_NDVI*) AND THE STANDARD DEVIATION OF NDVI USED IN THE ANALYSIS

YEAR	START NDVI COMPOSITE		END NDVI COMPOSITE	
	JULIAN DAYS	CALENDAR DAYS	JULIAN DAYS	CALENDAR DAYS
1995	034 – 040	FEB 3 – FEB 9	328 – 334	NOV 24 – NOV 30
1996	033 – 039	FEB 2 – FEB 8	327 – 333	NOV 22 – NOV 28
1997	031 – 037	JAN 31 – FEB 6	325 – 331	NOV 21 – NOV 27
1998	030 – 036	JAN 30 – FEB 5	324 – 330	NOV 20 – NOV 26
1999	036 – 042	FEB 5 – FEB 11	330 – 336	NOV 26 – DEC 2
2000	035 – 041	FEB 4 – FEB 10	329 – 335	NOV 24 – NOV 30
2001	033 – 039	FEB 2 – FEB 8	327 – 333	NOV 23 – NOV 29
2002	032 – 038	FEB 1 – FEB 7	326 – 332	NOV 22 – NOV 28
2003	036 – 042	FEB 5 – FEB 11	330 – 336	NOV 26 – DEC 2
2004	035 – 041	FEB 4 – FEB 10	329 – 335	NOV 24 – NOV 30
2005	033 – 039	FEB 2 – FEB 8	327 – 333	NOV 23 – NOV 29
2006	032 – 038	FEB 1 – FEB 7	326 – 332	NOV 22 – NOV 28
2007	037 – 041	FEB 6 – FEB 10	331 – 337	NOV 27 – DEC 3
2008	036 – 042	FEB 5 – FEB 11	330 – 336	NOV 25 – DEC 1
2009	034 – 040	FEB 3 – FEB 9	328 – 334	NOV 24 – NOV 30
2010	033 – 039	FEB 2 – FEB 8	327 – 333	NOV 23 – NOV 29

FIGURE 11:
MAP OF THE NORTHERN ROCKIES GRAY WOLF FEDERAL RECOVERY AREAS

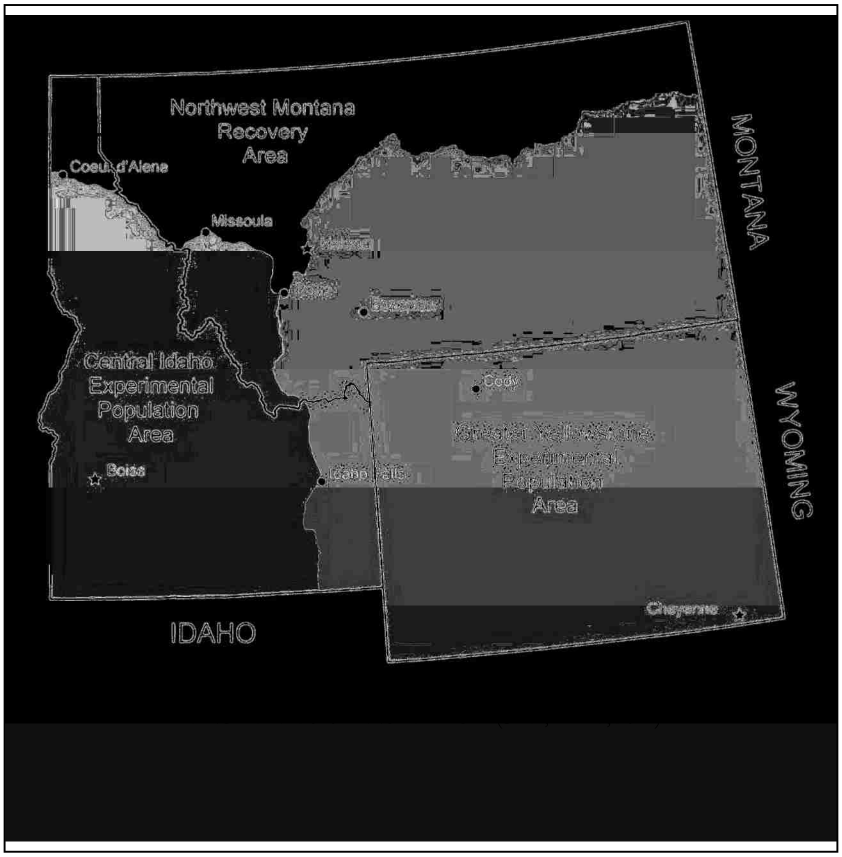

FIGURE 12:
USDA WILDLIFE SERVICE PRODUCER RELEASE FORM USED TO OBTAIN WILDLIFE SERVICE WOLF DEPREDATION INVESTIGATION REPORTS ON SAMPLE RANCHES

I, ___________________________________ allow Montana Wildlife Services to disclose information pertaining to cases of investigated depredation on the ranch that I own and/or manage to the research team at the University of Montana which includes Joe Ramler, Derek Kellenberg, and Mark Hebblewhite.

Ranch Name __________________________________

Signature _________________________________ Date ________________

FIGURE 13:
COPY OF THE RANCHER QUESTIONNAIRE USED DURING ON-RANCH INTERVIEWS

Survey # ________

Date: _______________

Rancher Name: ____

Address: ____

____

County: ______________________________

Phone Number: _______________________________

E-mail address: ____

Which way would you prefer to be contacted if need be? **E-mail** ______ **Phone** ______

---

1. What breed of calves do you raise? ____

(a) Have you ever raised any other breeds? **Yes** ______ **No** ______

(b) If yes, what other breed and when?

____

____

____

2. What breed of dams do you run? ____

(a) Have you raised other dam breeds in the past? **Yes** ______ **No** ______

(b) If yes, what other breed and when?

____

____

____

____

____

3. What breed of sire(s) do you use? ____

(a) Have you used other breeds of sires in the past? **Yes** ______ **No** ______

(b) If yes, what other breed and when?

____

____

____

4. Approximately, on what date is your first and last calf born?

Date of first calf birth: ________________________________

Date of last calf birth: ________________________________

(a) Is this consistent from year to year? **Yes** ______ **No** ______

(b) If no, during what year(s) did these dates differ? What are the different dates?

Year__________ **First birth date** _______________ **Last Birth Date** __________________

Year__________ **First birth date** _______________ **Last Birth Date** __________________

Year__________ **First birth date** _______________ **Last Birth Date** __________________

Year__________ **First birth date** _______________ **Last Birth Date** __________________

5. Do you ship and wean at the same time? **Yes ______** **No ______**

(a) If NO, do you weigh your calves at weaning? **Yes ______** **No ______**

(i) If YES, weaning weights are wanted.

(ii) If NO, shipping weights are wanted.

6. Approximately how many acres do you use to summer pasture your pairs?

____

____

(a) Has this changed over the years? **Yes ______** **No ______**

(i) If YES, how has this changed (bought or sold pasture land) and when?

____

____

____

7. Do you lease any land used for pasturing of your pairs further than 25 miles from your ranch?

Yes ______ **No ______**

(a) If YES, where are these leases and what years have you used them? ___________________

____

____

____

8. Do you hormone implant on steer calves? **Yes _____** **No ______**

9. Do you hormone implant on heifer calves? **Yes ______** **No ______**

(a) Is this consistent from year to year? **Yes ______** **No ______**

(i) If NO, please indicate how it has differed and in what years.

Year __________ Steers: Yes ______ No ______ Heifers: Yes ______ No ______

Year __________ Steers: Yes ______ No ______ Heifers: Yes ______ No ______

Year __________ Steers: Yes ______ No ______ Heifers: Yes ______ No ______

Year __________ Steers: Yes ______ No ______ Heifers: Yes ______ No ______

Year __________ Steers: Yes ______ No ______ Heifers: Yes ______ No ______

Year __________ Steers: Yes ______ No ______ Heifers: Yes ______ No ______

Year __________ Steers: Yes ______ No ______ Heifers: Yes ______ No ______

Year __________ Steers: Yes ______ No ______ Heifers: Yes ______ No ______

Year __________ Steers: Yes ______ No ______ Heifers: Yes ______ No ______

10. Have you ever sighted wolves on your ranch? **Yes ______** **No ______**

(a) If YES, was it alone, what color was it (or were they), when did you see it (them)?

____

____

____

____

____

____

11. Have you ever had a confirmed wolf kill (or kills) on your ranch? **Yes ______** **No ______**

(a) If YES, what was the date of the kill(s) and what was killed (calf, heifer, other)?

____

____

____

12. Have you had any "probable" confirmed wolf kills? **Yes ______** **No ______**

(a) If YES, what was the date of the probable confirmed kill(s) and what was killed?

____

____

____

____

____

____

13. Have you had any non-wolf confirmed kills (coyote, bear, mountain lion, eagle, fox, ect.)?

Yes ______ **No ______**

(a) If YES, on what dates did the kills occur and by what?

____

____

____

____

____

____

14. Has a neighbor had any wolf presence that you know of? **Yes ______** **No ______**

(a) If YES, what color was the wolf, how was this detected (i.e. confirmed kill, sighted, scat, tracks, ect.) and when?

____

____

____

____

____

15. What are your summer loss rates?

1995		**2002**	
1996		**2003**	
1997		**2004**	
1998		**2005**	
1999		**2006**	
2000		**2007**	
2001		**2008**	
2009			

16. How many calves did you sell?

1995		**2002**	
1996		**2003**	
1997		**2004**	
1998		**2005**	
1999		**2006**	
2000		**2007**	
2001		**2008**	
2009			

Please indicate any other information about your specific husbandry practices and/or any changes you've made over the years that you think are a critical influence on the weight gain of your calves.

____

____

____

____

____

____

____

FIGURE 14:
MAP OF WILDLIFE SERVICES CONFIRMED DEPREDATIONS. ALL CONFIRMED DEPREDATIONS ON SAMPLE RANCHES WERE DUE TO WOLF PREDATION. NO WS INVESTIGATIONS PERTAINING TO OTHER PREDATOR DEPREDATION (I.E. BEARS, COYOTES, MOUNTAIN LIONS, ETC.) WERE CONDUCTED ON SAMPLE RANCHES DURING THE TIME PERIOD OF THE STUDY.