THE IMPACT OF WOLVES ON ELK HUNTING IN MONTANA

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ABSTRACT

The controversy over gray wolves has been a continual debate throughout the American West since reintroduction in the mid 1990's. Hunter stances on this issue vary across the state since the true impact of these predators is unknown. Following wolf recovery, researchers have found game numbers decreasing in some regions while remaining steady in others. Areas with game reduction have been found to have higher populations of predators, including grizzly bear, cougars, and wolves. Recently, Montana wolves have been taken off the federal list of endangered species, allowing the state game agency to manage populations. The purpose of this thesis is to develop a method to analyze the impact of wolves on elk harvest and a proxy for hunter demand throughout three distinct regions. A system of equations derived from overall biological models was used to form the basis of the empirical models. The dependent variables that are developed assess the impact of wolves on the quantity of both elk harvest and hunter applications. The wolf variables included in the models capture the population of wolves and how their impact changes as hunting moves farther away from reintroduction areas. The time period considered is from 1999 to 2010. Data prior to 1999, when wolves were first reintroduced to Yellowstone National Park (YNP), has not been released by Montana Fish, Wildlife and Parks (MFWP), therefore limiting this analysis. The results from the empirical estimations suggest wolves are reducing overall hunter demand in both the southwest and west central regions. In particular, the southwest region is seeing a shift in hunter applications from areas less than 25 miles to YNP to areas ranging from 25 to 50 miles. No statistically significant regional effect of wolves on hunter harvest was found in any region analyzed.

INTRODUCTION

The controversy over gray wolves has been a continual debate throughout the American West since reintroduction in the mid 1990's. In 2011, the Northern Rockies wolf population rose despite the removal of federal protections in Montana and Idaho. An article in the *Billings Gazette* by Steve Guertin discusses the increase of wolves in the Northern Rockies and states, "The animal's number rose by more than seven percent to 1,774 wolves, as state officials look for more ways to reduce the population under pressure from hunters and ranchers who blame the predators for livestock and big-game losses." Wolves mainly inhabit Idaho, Montana, and Wyoming, though their distribution extends to parts of Washington, Oregon, and Utah as well. Montana held their second wolf hunt in 2011 with hopes of reducing the state population by 25 percent, but numbers actually rose by 15% to 653 wolves. State officials blame the rise in population to a hunt that fell short of the quota of 220 wolves and to wildlife officials, who killed fewer problem wolves than in previous years. The increase has been met by criticism from county officials who claim Montana Fish, Wildlife and Parks (MFWP) regulators aren't doing enough to take on the predator problem. On March 7th, 2012 more than a dozen county representatives expressed their concern to MFWP commissioners, emphasizing restrictions needed to be loosened so that more wolves are killed in the coming year. Recommendations such as reducing the price of the non-resident license from $350 to $50 and allowing hunters to kill more than one wolf are all being considered for the 2012 wolf hunt (Guertin, 2012).

Through the reintroduction process wolves have once again gained a place in the environment. One of the most controversial issues is how to manage the population of these animals so that people can still enjoy the hunting activities to which they've grown accustomed. Weeden (as cited in Mech and Boitani, 2003) discusses how opposing wolf control can have large scale environmental and economic costs through reductions in renewable game from natural systems. Reducing game increases society's reliance on energy-intensive domestic food, and carries high environmental costs, such as elimination of wild habitat. Today few people support the extermination of wolves. Rather the issue is how to balance the system, providing a reasonable share of wildlife for both wolves and humans (Mech and Boitani, 2003).

In 2009, MFWP released a report by Hamlin and Cunningham describing the impact of wolves on game species in Montana. The state's elk population was found to vary by region and presence of other large predators such as grizzly bears. The data for southwest Montana indicated calf survival rates following wolf restoration remained similar to rates prior to restoration. Areas that did show declines in calf survival were occupied by both wolves and grizzlies. The same areas also showed an increase in mule deer populations. In Region 1, moose numbers have been stable and or increasing and in most of the state white-tail buck harvest has been increasing steadily. While game populations appear to be somewhat normal, hunters throughout Montana are concerned about the impact of these predators.

Agriculturists are an additional group in opposition to wolves since these predators can impact their livelihoods. Individuals in this industry generally view wolves as vicious predators and killers of livestock, blaming them for livestock depredations even when evidence may imply other predators. This may lead to a misperception of the depredation problem. In Alberta wolves were confirmed in only 36% of livestock killings (Gunson, 1983). In Wisconsin they accounted for 49% and in northwestern Montana 25% (Treves et al. 2002; E.E. Bangs, USFWS, personal communications). In 1991, cattle producers in eighteen western states reported 1,400 cattle lost to wolves, 1,200 of which were reported in areas uninhabited by wolves (National Agricultural Statistics Board, USDA, 1992; Bangs et al. 1995). On the other hand, in certain areas where wolves have recolonized they have lived up to their reputation. In Sweden during 1977, wolves killed 80 to 100 reindeer in only a month (Bangs et al. 1995). Though it is true wolves kill livestock, in many cases they are blamed as the culprit even when information points to other predators, potentially leading to a misconception of their true impact [Gunson, 1983; Treves et al. 2002; National Agricultural Statistics Board, USDA, 1992; Bangs et al. 1995; E.E. Bangs, USFWS, personal communications; (as cited in Mech and Boitani, 2003)].

While some groups oppose wolves, others value the knowledge that they exist in the wild. This type of value may be estimated through surveys and interviews by asking people their willingness to pay for wolf tourism. For example in 1992, Duffield (as cited in Mech and Boitani, 2003) estimated the annual existence value of wolves per year was $8,300,000 in Yellowstone National Park (YNP) and $8,400,000 in Idaho. It must be noted that no attempt was made to estimate the negative value of wolves which would likely offset these hypothetical values.

The purpose of this thesis is to develop a method to analyze the impact wolves are having on the harvest of elk as well as how hunters are reacting to the presence of these wolves. By using a recursive system the impact of wolves on the harvest of elk and changes in hunter permit applications may be estimated. Through the results of this analysis hunters may be able to better understand the true impacts of these animals. This paper will hopefully educate individuals on the issue of wolves and elk, allowing them to determine their stance on the issue more accurately. The results of this study imply wolves may be decreasing the number of hunter applications in the west central and southwest regions of the state. Southwest Montana in particular is seeing a shift in applications from areas in close proximity to YNP to areas further away.

The analysis in this thesis proceeds as follows. First, information on the life and history of wolves is provided in Chapter 2. Chapter 3 reviews relevant literature pertaining to this topic. Chapter 4 provides a discussion on the data used in empirical estimations. Chapter 5 discusses elk hunting licenses in the state of Montana. Following this discussion a system depicting the relationship of wolves, hunters, and game is developed. Chapter 6 discusses the models, statistical procedures, and results of the empirical estimation. Lastly, conclusions on the response of hunters and the impact of wolves on elk hunting throughout Montana are reported in Chapter 7.

THE HISTORY AND BIOLOGY OF WOLVES

2.1 Wolves

Gray wolves (Canis lupus) are social animals that live, travel, and hunt in packs. They are the only large predator in North America that is dependent on a cooperative social unit for survival. A pack is formed when a male and female mate. The pack is made up of this alpha pair, their offspring from the previous year, and new pups. The social structure consists of the alpha pair, the beta wolf or second in command, various subordinates, and the lowest member of the pack called the Omega (Living with Wolves, 2007). In the Northern Rocky Mountains the average pack size is 10 wolves. In recent years one pack in YNP was documented to have 37 members, however the pack eventually broke up into several smaller groups (USFWS Q and A, 2011).

2.2 Biology

The gray wolf ranges in size from five to six feet in length, measured from nose to tail. An adult wolf can weigh between 70-120 pounds, but Montana wolves generally weigh 90 to 110 pounds for males and 80 to 90 pounds for females. The animals can be tan, brown, black, white or gray-silver in color, while their eye color can be yellow, green, or brown. Wolves have an undercoat that is as dense as wool and an outer coat consisting of a double layer of outer guard hairs. The outer coat is so efficient wolves can lie completely exposed to winter elements. Snow that accumulates will not melt since so little heat escapes their thick coat. Wolves may be mistaken for coyotes and some breeds of dogs, particularly when they are young. Some distinguishing characteristics of wolves are their long legs, wide head and snout, narrow body, straight tail, and tracks that range from 5 to 5.5 inches long, 4.5 inches wide, with claws evident (MFWP Regulations, 2011; Living with Wolves, 2007).

2.3 Reproduction

In the Northern Hemisphere wolves copulate in winter and have a gestation period between 61-64 days. Preparations for pup care begin in autumn with the digging of a den site. Dens are located in the middle of the territory, minimizing hostile encounters with neighboring packs. Pups are born in the spring coinciding with the birth pulse of herbivores. By autumn, they are large enough to follow adults hunting larger prey animals (Mech and Boitani, 2003). In northwestern Montana between 1982 to the mid 1990's the average litter size was 5.3, ranging from one to nine pups (MFWP Final EIS, 2003).

The development of wolves is similar to dogs with four developmental periods: (1) neonatal, (2) transition, (3) socialization, and (4) juvenile. The neonatal period is the period from birth to the age when eye opening occurs. Pup senses develop during this time. The transition period is the phase between eyes opening to 20 days. During this time, coordination develops allowing the pups to stand and walk. The socialization stage is from 20 to 77 days when the transition from milk dependency to solid food occurs. They are now old enough to begin exploring and playing outside the den. As pups' independence from milk progresses, adult wolves are bombarded with adolescences poking their muzzles. This action is called "lick-up" and if the adult has a full stomach, stimulates regurgitation of food. Finally, the juvenile period is from 12 weeks to maturity when pups learn hunting techniques (Mech and Boitani, 2003).

Pup survival is dependent on several factors, such as disease, predation, and nutrition. In northwest Montana 85% of pups survived until December between 1982 and 1995. After reintroduction into YNP, 133 pups were born in 29 litters. By the end of 1998, 71% of pups were believed to still be alive and well (MFWP Final EIS, 2003).

2.4 Diet

The gray wolf is an opportunistic carnivore that preys on a wide range of prey, from ungulates to rodents. Wolves are highly adapted to hunting prey species such as deer, elk, and moose, but they will scavenge carrion and even eat vegetation. In Montana wolves mainly prey on white-tailed deer, mule deer, elk, and moose. The relative abundance of each ungulate species in a territory determines the pack’s diet. In 1999, white-tailed deer comprised 83% of northwestern Montana wolf kills, while in YNP 87% of wolf kills were elk. Wolves have been known to scavenge opportunistically on road kill, winterkill, and kills made by other large carnivores. Wolves may also kill domestic livestock and dogs but usually do not feed on the carcass of dogs (MFWP Final EIS, 2003).

2.5 Hunting Tactics

Wolf hunting tactics can be broken down into several stages: (1) locating prey, (2) the stalk, (3) the encounter, (4) the chase, and (5) the kill. In order to make a kill, wolves must first locate their prey; to do this they must use all of their senses. Scent is the primary means of detection, while tracking, chance encounters, and observation from vantage points also help in locating prey. Once prey is located they will attempt to get closer, often using gullies and other uneven terrain to aid in their stalk. Next the encounter phase of the hunt begins, when wolves and prey meet. Prey may stand their ground or they may flee. When large prey stand their ground wolves are presented with a dilemma, since they generally wait until the prey flee before taking action. If the prey refuse to flee wolves may remain up to four hours, periodically trying to get them to run. Once prey animals flee, the chase portion of the hunt begins. In general, the chase phase does not last long, although there are exceptions. Wolves have chased, tracked, and followed deer for up to 21 km and chased caribou for 8 km. In most cases this distance is much shorter. The victims of wolves are almost always vulnerable in some way, therefore it's believed wolves use the chase as a way to study and evaluate their prey. In some instances wolves have been observed chasing moose but never attacking. On other occasions wolves attack and kill. These examples of wolves abandoning and pressing attacks suggest wolves estimate the vulnerability of individual prey in various situations (Mech and Boitani, 2003).

Biologists agree wolves are a highly intelligent species that learn quickly and show insightful behavior. Thus it's likely wolves develop cooperative hunting strategies such as using teamwork, relay running, ambushing, and decoys. The degree to which these strategies are used is unknown. It seems logical that a wolf's primary adaptation for hunting is its social nature, yet evidence suggest otherwise. Packs of wolves actually kill less food per wolf than pairs of wolves. Whether pairs are more efficient than a single wolf is unknown. The reason being is that packs larger than two adults are made up of primarily young and less experienced wolves that contribute little to the hunt (Mech and Boitani, 2003).

2.6 Territories

Each pack establishes its own territory boundaries and defends them from trespassing wolves. Between April and September, pack activity is centered on den and rendezvous sites. After September when the pups are old enough the pack hunts throughout its remaining territory until the following spring.

At the beginning of wolf reintroduction it was assumed higher elevation public lands would comprise the primary habitat for wolves. While some packs have established backcountry territories the majority seem to prefer lower elevations where prey is more abundant. This finding contradicts assumptions that wolves do not tolerate human presence or disturbance. Wolves are now using and traveling on private lands where they are in close proximity to humans and livestock. The size of pack territories vary based on the size of the pack. The earliest-colonizing wolves had the largest territories averaging 460 square miles (mi^2). In recent years, the average territory has decreased. During 1999, average territories in northwestern Montana were 185 mi^2. Central Idaho (CID) and Greater Yellowstone Area (GYA) packs patrolled larger territories averaging 360 mi^2 and 344 mi^2 (MFWP Final EIS, 2003). Once wolves reach sexual maturity, some will remain with the pack while others will disperse in order to find a mate and start a new pack. Dispersal wolves may move to unoccupied territories near their original pack's territory or may travel several hundred miles before locating suitable habitat. Boyd and Pletscher (1999) determine that disperser wolves often move to higher wolf density areas.

Implications of this finding are significant for Montana, since wolf packs are now located to the south and west in Wyoming, YNP, and Idaho. Thus dispersal will lead to a larger regional population, with a more diverse gene pool.

2.7 The History of Gray Wolves

Native American Indians shared a deep respect for wolves. While the wolf was hunted, it was also appreciated and respected. Tribes admired the intelligence, courage, and strength of the creature and often referred to the species as the Pathfinder or Teacher. Tales were handed down from generation to generation portraying the wolf as the devoted family member, skilled hunter, true survivor, and heroic defender of territory. To the Native American Culture these were traits that deserved respect. To show their admiration of this creature, Native Americans often celebrated the wolf in ceremony, legend, as well as song and dance. These views do differ between hunting and farming tribes, for example the Navajo, referred to the wolf as mai-coh, meaning witch. Their fear was not based on the nature of wolves rather on human nature. They believed human witches used the power of wolves to hurt or abuse people. Although it is not possible to trace the relationship between wolves and humans, the relationship most likely extends back at least two million years. A time when wolves and humans shared similar ways of life; traveling in small family groups and killing what they could to survive (The Symbolic Wolf, 2011).

On the other hand Europeans viewed wolves as unfavorable because they killed livestock. The campaign to eliminate wolves from North America began when Pilgrims arrived from England. When livestock arrived in Jamestown, VA, during 1609, the

Plymouth Colony enacted the first wolf bounty. Soon after other settlements along the eastern seaboard established bounties. By 1700, wolves had disappeared from New England. When settlers moved west, hunters were temporarily diverted from wolves and focused on herds of bison and game. The immense number of carcasses left by bison hunters may have fostered an increase in the wolf population but this was soon reversed when revived interest in wolf pelts encouraged hunters to once again kill these animals. By 1870, the expansion of the livestock industry to the west and the coinciding disappearance of game animals caused an increase in wolf predation on livestock. The extermination of all predators became a focus point for landowners and authorities. Between the years 1870 to 1877, approximately 100,000 wolves were killed in Montana alone (Mech and Boitani, 2003). In Montana the first statewide bounty law was passed in 1884; 5,450 hides were presented for payment during this first year. Between the years 1900 to 1931 all but three Montana counties reported bounty payments for wolves (MFWP Gray Wolf, 2011). In 1915, the war on wolves became the responsibility of the U.S. government with the establishment of the Division of Predator and Rodent Control (PARC). Wolf hunting became an obsession and hunters were paid full-time to kill the last wolves (Mech and Boitani, 2003).

Methods used in the extermination included trapping, digging up den sites, killing pups, shooting on sight, and poisoning animal carcasses with strychnine (USFWS Gray Wolf, 2003). By 1930, the gray wolf was extinct in Montana. In 1967 the USFWS listed the eastern timber wolf as endangered. In 1973 the Northern Rocky Mountain species was also listed as endangered. Finally, in 1978 the legal status of all wolves south of Canada was listed as endangered (MFWP Gray Wolf, 2011).

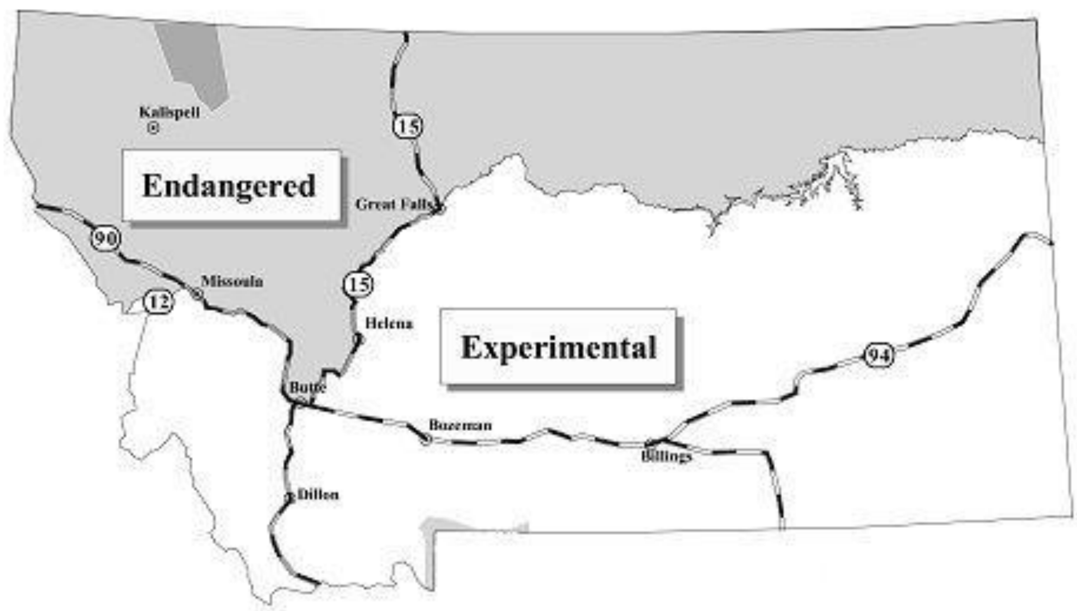
2.8 Reintroduction

In 1980, a plan was conceived by the Northern Rocky Mountain Recovery Team that would guide wolf recovery efforts for future populations. The plan was revised in 1987, and designated three recovery areas: Northwestern Montana, Central Idaho, and the Greater Yellowstone Area. Gray wolf numbers began to expand their population and distribution in Montana due to natural emigration from Canada. In 1986, the first den in fifty years was documented in Glacier National Park. By the end of 1994, approximately 48 wolves inhabited the area around the Park (MFWP Gray Wolf, 2011).

In 1995, a total of fourteen Alberta-born gray wolves were reintroduced into YNP, following a seventy-year absence from this environment. The wolves were held in acclimation pens for ten weeks. After their release, two of the females denned and produced nine pups. Fifteen wolves were also reintroduced into the wilderness of central Idaho during this time. These wolves did not settle in the area of reintroduction, rather they moved wildly throughout the state. In 1996, an additional seventeen wolves were released in Yellowstone and twenty wolves were released in central Idaho. After this time, populations in both Yellowstone and Central Idaho grew rapidly. New packs formed throughout the areas, which contributed to the continual wolf dispersion into Montana. By the end of 2002, the northern Rocky wolf population met the recovery criteria of thirty breeding pairs. By the end of 2004, the three states combined to have a population of 835 wolves and 66 breeding pairs (MFWP Gray Wolf, 2011). In 2004, the

U.S. Fish and Wildlife Service (USFWS) approved the Montana Gray Wolf Conservation and Management Plan, but delisting of wolves in the northern Rockies was postponed. Later in 2004, when federal funds became available, MFWP began managing wolves in northwestern Montana under a cooperative agreement with the USFWS. In 2005, the agreement was expanded statewide and allowed Montana to implement its own federally approved plan within the guidelines of federal regulation. Through the use of federal funds, MFWP has been able to monitor populations, perform wolf control, and lead in wolf education/research programs (Sime et al, 2011).

In February 2008, the USFWS delisted the gray wolf in all of Montana, Idaho, Wyoming, eastern Oregon, eastern Washington, and a small part of Utah (Northern Rocky Mountain Distinct Population Segment). The decision was challenged in court in April, and in July, a preliminary injunction was granted, putting wolves back under federal regulations. In Montana wolves were relisted as endangered or experimental. Then in April 2009, USFWS published a new delisting decision that took the grey wolf off endangered species status in all of Montana, Idaho, eastern Oregon, eastern Washington, and a small part of Utah; Wyoming wolves remained listed as endangered or experimental. Upon the delisting, the gray wolf was reclassified as a state species and the first fair chase wolf hunt occurred in the fall of 2009. Management under MFWP only lasted until August 5, 2010 when a federal court ordered wolves to be put back under the protection of the Endangered Species Act. In Montana, this meant wolves in the northern half of the state were reclassified as federally endangered, while wolves in the southern half were reclassified as experimental (Sime et al, 2011). The distinction between the two areas are, experimental wolves can be shot if seen attacking dogs or livestock while endangered wolves are subject to additional protection and livestock owners are prohibited from killing problematic wolves (Endangered Species Act, 2010).

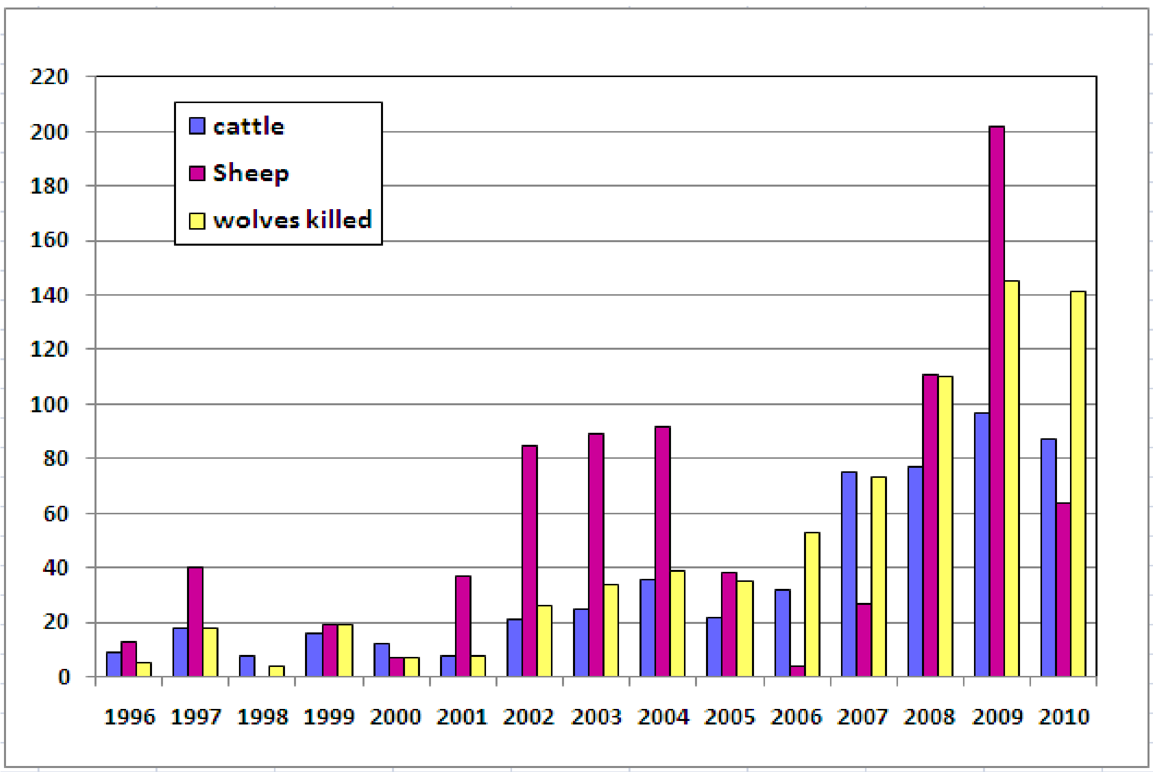


Source: MFWP Annual Report, 2010
Figure 2.1 Map of Endangered and Experimental Zones in MT

Finally, on May 5, 2011 wolves in portions of the Northern Rocky Mountain Distinct Population Segment were removed from the Federal List of Endangered and Threatened Wildlife. In Wyoming, wolves will remain under the ESA, until a wolf management plan is developed that allows wolves to be removed from the list. In order for Montana to avoid relisting, the state will have to comply with federal regulations to manage wolves in a manner that guarantees a state minimum of 150 wolves and 15 breeding pairs. Through the delisting, Montana will be able to manage wolves similar to bear, mountain lions, and other wild predator species. Wolves will be reclassified as a species in need of management statewide and the line separating Montana in the northern Endangered Area and the southern Experimental Area will no longer exist.

There are three scenarios that could cause wolves to be relisted as an endangered species. First, if the population falls below 100 wolves or 10 breeding pairs in Montana, Idaho, or Wyoming. Second, if the population of wolves in any of the states listed above falls below 150 wolves or 15 breeding pairs for three consecutive years. Lastly, if a change in state management or law increases the threat to the species (FWP Fact Sheet, 2011).

Many citizens are concerned about the impact wolves have on livestock. Although it is true wolves occasionally feed on livestock, they primarily feed on big game animals, such as elk and deer. Throughout Montana between the years 1987 to 2006, a total of 230 cattle, 436 sheep, 12 llamas, 3 horses, and 2 goats were killed by wolves (Sime et al, 2007). To combat these losses USFWS and the State of Montana work with livestock producers to reduce the risk of predation. Although, with a growing wolf population that increased by 8% between 2009 and 2010, Montana may see even more conflicts with livestock. The wolf count of 566 wolves in 2010 consisted of 108 packs and 35 breeding pairs. Northwestern Montana had approximately 326 wolves in 68 packs. In western Montana there were 122 wolves in 21 packs, and in southwestern Montana, there were 118 wolves in 19 packs. Since wolves already occupy the most suitable habitats, the expanding populations have increased their conflicts with livestock; hence wolf control has also increased. This dynamic process shows more of a turnover effect at local scales rather than a net increase. Evidence of this relationship is found in western and southwestern Montana, where wolf populations have oscillated between 110-130 wolves in past years. Contrary to other parts of Montana the northwestern portion of the state's wolf population is still rising. One contributing factor is that livestock availably is lower in this area. Hence, lethal control isn't an inhibiting factor, relative to the rest of the state (Sime et al, 2011).



Source: MFWP Annual Report, 2010
Figure 2.2 Confirmed Livestock and Sheep Depredation in MT (1996-2010)

According to the U.S Fish and Wildlife Service, confirmed livestock depredation by wolves decreased between 2009 and 2010. During this time period there were 199 cattle, 249 sheep, 2 dogs, and 15 other livestock such as llamas, goats, and horses lost to wolves. Of the 260 wolf packs outside of YNP in 2010, 64 (25%) packs were involved in at least one confirmed livestock or pet depredation. This is down from 2009 when 32% of packs outside of YNP were involved in at least one livestock depredation (USFWS Rocky Mountain Wolf Recovery, 2010).

Table 2.1 Wolves Killed by Private Citizens in Defense of Property

Year	Wyoming	Idaho	Montana
1995-2000	0	0	2
2001	0	0	0
2002	0	0	1
2003	2	0	0
2004	2	0	0
2005	1	3	7
2006	1	7	2
2007	0	7	7
2008	0	14	7
2009	0	6	14
2010	0	13	16
Total	6	50	56

Source: Obtained from USFWS Rocky Mountain Wolf Recovery, 2010

Public concern has also been expressed regarding the hunting industry and the loss of hunting opportunities due to wolves. Research in Montana has shown predation in general will influence game populations through survival of young, death of adult animals, or a combination of the two. Predation impacts are a combination of various factors such as drought, severe weather, carnivore density, and habitat conditions. In general, wolves are only one additional factor for biologists to consider when setting game regulations.

2.9 Wolf Hunting and Funding

Montana law will allow wolves to be killed only during official hunting seasons authorized by the FWP Commission. If wolves are seen killing or threatening humans, livestock, or pets, lethal force is permitted. According to MFWP, the hunting season will be a science-based effort focused on creating a balance among wildlife, humans, and the environment. Quotas for the hunting season will be tracked by requiring hunters to call FWP upon success of a hunt. Once a management unit quota is filled, the season will close after a 24-hour notice. The season dates will vary but will likely correspond to Montana's early backcountry and general big game rifle season. The licensing fees are $19 for residents and $350 for nonresidents (FWP Fact Sheet, 2011).

The cost of wolf management increased during the 2010 Fiscal Year. During this time federal agencies spent $4,556,000, which included $1,103,000 by the USDA to investigate reports of wolf predation and to control problem wolves. Private and state compensation programs also paid $453,741 for livestock damage caused by wolves. In 2010, wolf compensation in Montana was $96,097, in Idaho $270,263, in Wyoming $82,186, in Oregon, $4,335, in Washington $463, and in Utah $397. In 2011, it is estimated $4,765,000 of federal funding will go towards wolf management. MFWP's primary budget source for wolf management comes from hunting and fishing throughout the state. If wolves are negatively impacting game populations then they are also impacting how MFWP can actively manage them their own population (USFWS Rocky Mountain Wolf Recovery, 2010).

REVIEW OF RELEVANT LITERATURE

3.1 Studies of Wolf Impacts on Ungulate Populations

The study of gray wolves by the Yellowstone Wolf Project began when fourteen Alberta-born wolves were released in Yellowstone National Park (YNP). Since that time the project has studied all aspects of their lives including wolf-prey interactions. In 2007, staff of the Wolf Project detected 323 total kills by wolves comprising of 272 elk, 11 bison, 7 wolves, 4 deer, 4 coyotes, 3 moose, 2 black bears, 1 pronghorn, 1 golden eagle, 1 red fox, 1 otter, and 16 unknown kills. Elk comprised 84% of the kills made in the park during this time. Of those elk, 41% were bulls, 21% calves, 28% cows, and 10% were unknown (Smith et al, 2008). In 2010, project staff detected 269 kills made by wolves comprising of 211 elk, 25 bison, 7 deer, 4 coyotes, 4 wolves, 2 moose, 2 pronghorn, 2 grizzly bears, 2 ravens, and 10 unknown. Of the elk killed, 18% were comprised of bulls, 25% calves, 43% cows, and 15% of unknown sex. Due to ecological significance and public controversy, wolf and elk interactions continue to be a primary focus of predation studies in YNP. Since the reintroduction of wolves to Yellowstone, the northern range elk population has declined by 50 percent. Although wolves are one factor, park scientist maintain other factors such as weather patterns, management of elk outside of YNP, and other predators influence forage quality/availability, therefore also contributing to the decline (Smith et al, 2011).

By capturing wolves and radio-collaring them, biologists have been able to track their movements as well as observe kills made by packs. In winter months, the majority of the kills are observed in lowland habitats despite an even distribution of prey in the uplands and lowlands. Human influence also seems to factor into where wolves choose to hunt. In areas that have moderate kill rates by humans, combined with high wolf densities, approximately ten percent of elk populations are killed during winter months. On the other hand, areas that have high kill rates by humans combined with low wolf densities result in a far lower estimate of only four percent of elk populations being killed. These observations suggest the effect wolves have on elk differ substantially on small spatial scales, dependent on a complex suite of interacting factors (Fuller and Keith, 1980; Garrot et al, 2005).

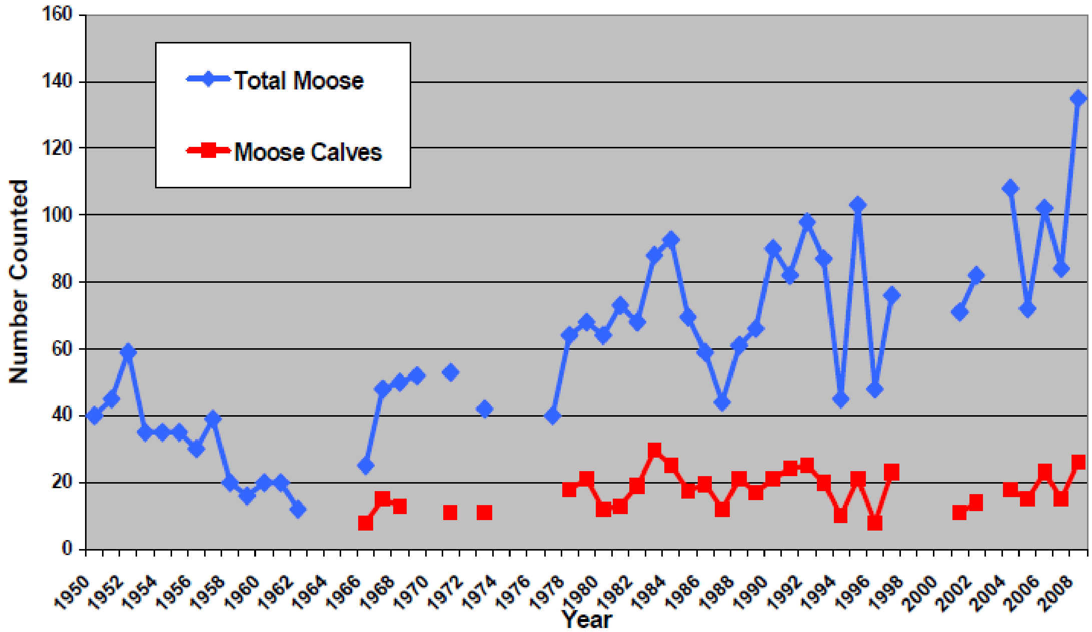
In a study by Hebblewhite (2005) the North Pacific Oscillation (NPO), a climatic index, is examined using a 15-year time-series of three elk subpopulations. Higher NPO values reflect increases in winter severity, and therefore reduce elk population growth regardless of wolf predation. However, in areas with wolf predation the elk population growth declines more severely. The study suggests that overall climate is an important factor in elk populations, though wolves do seem to speed up the decline. Hebblewhite et al. (2002) study the Bow Valley of Banff National Park. This study analyzes the effects of wolf predation, snow depth, elk density, and human-caused mortality on elk populations. A generalized linear model is used and finds that in low wolf predation zones, elk population growth is density dependent and limited by human-caused mortality. In zones where wolves are present, the population growth is limited by snow depth and wolf predation.

Wilmar and Getz (2004), conclude elk carrion is a crucial food resource for scavengers. Their model reveals that although wolves reduce the size of the elk herd, they smooth out the temporal distribution of carrion providing carrion throughout the year, when it was previously only available at the end of winter. Elk health on the other hand, improves during post wolf periods due to better grazing opportunities. Reductions in herd population lead to higher biomass ratios for the remaining herd, therefore providing better nutrition.

In 2009, Hamlin and Cunningham published a report summarizing elk-wolf interactions throughout Montana. According to the study, wolf numbers have increased dramatically since restoration in 1995, at rates between ten and thirty-four percent annually. Within southwest Montana and the Greater Yellowstone Area elk are the primary prey of wolves. Winter kill rates vary wildly across the region ranging from 7 to 23 elk per wolf. It appears summer elk kill rates are lower than winter months, however there is limited data pertaining to the summer season. Even though elk are the main prey of wolves, in most areas survival rates of elk calves have been similar to survival rates prior to wolf restoration. In areas such as the Gallatin-Madison range and northern YNP where wolf and grizzly bear densities are high, calf survival rates have recently been recorded at half or less than half compared to levels prior to wolf restoration. Adult female survival rates are around 80 percent within these areas. This survival rate is similar to historical trends that range from 75-85 percent. It is important to note, grizzly bear populations especially in southwest Montana and GYA have increased threefold since 1987. In areas with fewer predators present, elk numbers have remained stable or have increased in recent years. Hence, the combination of human, grizzly bear, and wolf predation may greatly influence the size of elk herds. Data collected during winter months indicate wolves influence elk distribution and movement rates. Upon contact with wolves elk will displace up to 1 km and will increase movement up to 1.23 km every four hours. In areas where hunting, hunting access, and wolves have been studied simultaneously, hunter impacts on elk distribution, group size, and habitat selection has been larger than any effect from wolves. In the Madison-Firehole area, data indicates wolves influence large scale migration patterns, while in other areas there is no measurable effect on herd migration.

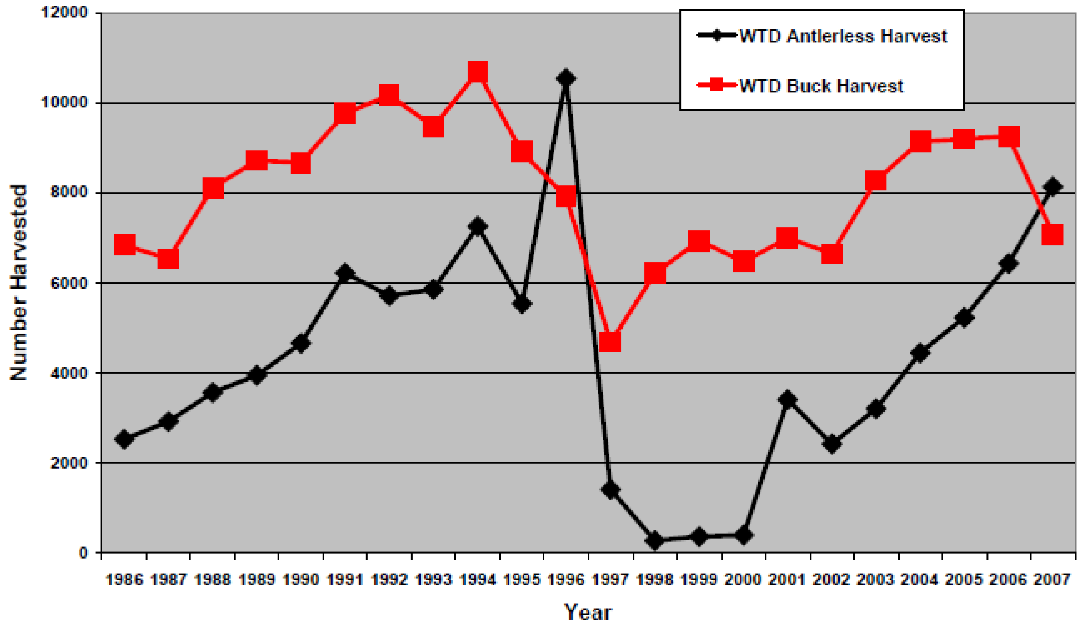
According to MFWP, mule deer are rarely preyed upon by wolves in southwestern Montana, but they are of particular interest to biologists because they serve as a good control species when studying elk in the region. Their distributions overlap elk and wolves and their recruitment and populations dynamics are susceptible to drought. In hunting district 313 mule deer recruitment followed the same annual pattern of elk calf recruitment in the northern range of Yellowstone until the spring of 1999. Besides a non-significant decline of mule deer numbers in hunting district 392, mule deer recruitment in all other portions of southwestern Montana have shown an increasing trend since 1995 (Hamlin and Cunningham, 2009).

Moose throughout Montana are also of particular concern since they occur in low numbers, therefore if preyed upon heavily their populations could dramatically decrease. In hunting district 334, near Red Rocks National Wildlife Refuge, moose counts have increased through 2008. Moose calf recruitment has remained steady since 1978. Prior to 1997 recruitment rates were around 36 calves per 100 adults. Since 1997, the recruitment rate has fallen to 23 calves per 100 adults however; this is offset by an increase in cow moose producing calves. In the Big Hole hunting districts, moose count and calf recruitment has declined. This decline began in the mid to late eighties; prior to wolf restoration therefore it is not thought to be correlated with wolf predation. In the Gallatin Canyon moose numbers have also declined, but due to inconsistent data the cause of this decline cannot be determined (Hamlin and Cunningham, 2009).



Source: Obtained from the Wolf-Ungulate Interactions Final Report by Hamlin and Cunningham (2009)

Figure 3.1 Moose Population Trends in HD 334 and the Southern Portion of HD 330



Source: Obtained from the Wolf-Ungulate Interactions Final Report by Hamlin and Cunningham (2009)

Figure 3.2 Region 1 Total Harvest of Antlerless and Antlered White-tailed Deer

As for white-tailed deer the influence of wolves varies. In Region 1, the white-tail population increased steadily until 2006 after a decline after the winter of 1996-97. The recent high was slightly lower than previous highs and occurred during a period of increasing wolf numbers. Total buck harvests have declined starting in 1994 but this is attributed to an increase in antlerless harvest throughout the region. In hunting district 110, which encompasses the North Fork of the Flathead River, white-tail deer have been found to be the primary prey of both wolves and cougars. In this region deer comprise eighty-three percent of wolf diets and eighty-seven percent of cougar diets. Throughout the mid-nineties an estimated 10 wolves, 70 cougars, 64 grizzlies, and 200 black bears per 1,000 km^2 occurred in much of HD 110. The high number of predators present in the environment undoubtedly had an effect on prey populations. Following the addition of wolves to the environment white-tail deer numbers saw a 15 year decline, but then recovered to previous highs. If this population trend is any indication, cycles of predator and prey abundance may develop throughout the state. While predator numbers in this region impacted average deer numbers they did not hold prey at permanently low numbers (Hamlin and Cunningham, 2009).

A field study by Thompson (1952) uses scat analysis to study food habits of timber wolves in Wisconsin. The study takes place during the period of 1946-1948 and focuses on the age of deer killed by wolves. By examining hair follicles in wolf scat, Thompson is able to distinguish between adult hair and the hair of fawns. Another useful tool for fawn identification during summer months is the remains of tiny hoof, tooth, and bone fragments within the scat. While in later months such as May and early June, thick white hairs from winter coats appear intermixed with incoming summer pelage, thus identifying adult deer. Thompson finds of the 148 scats collected during the summer months (May 21 to August 31), 141 contain the remains of deer. Of the 141 kills, fawns comprised 45%, adults comprised 50%, and 5% are unclassifiable. Overall 435 wolf scats are collected and whitetail deer remains occur in 97% of the scats, implying deer are the staple food of wolves in northern Wisconsin. Rodents and snowshoe hare comprise a small part of the wolves' diets at nine percent. This study helps to confirm wolves adjust diet selection to the most available ungulate in the area and often prey exclusively on these species, substituting other prey only when needed.

Adams et al. (1995) observed prey selection of wolves in Denali National Park throughout 1986 to 1992. The remains of 294 moose, 224 caribou, and 63 sheep are analyzed. Since bias is present in kill data due to the fact that larger ungulates are easier to spot, researchers use two approaches to analyze the data. First kills are observed directly. Second, it is assumed that wolves spend given periods of time consuming individual species. Therefore, the number of each age, sex, and species of prey are multiplied by the reciprocal of the assumed weight of each prey species giving an adjusted proportion. By correcting for measurement bias researchers determine that in a natural system, wolves can survive on vulnerable prey during moderate weather, but once snowfall exceeds average they switch to newly vulnerable prey and greatly increase their numbers. In this study moose formed the largest composition of wolf kills during the first four years. Caribou predominated during 1989-1991. As caribou kills increased both moose and sheep kills decreased. Throughout the study wolves showed a high degree of selectivity in predation patterns, however vulnerability proved to be the common factor in prey selection. In this instance vulnerability took various forms such as: youth, old age, poor condition, and hindrance by snow, varying both by time of year and species. Calves seemed to be important during summer months when they were at their weakest, male animals before, during, and after the autumn rut and cow animals during late winter when pregnancy and snow depth reduced their nutritional state. The population trends of moose and sheep were not known throughout this period, but overall there was no drastic decline observed. Caribou, on the other hand, increased in numbers. The main difference with this study compared to other similar studies is that in most areas either wolves or their prey are susceptible to human-caused mortality, but in Denali National Park hunting is forbidden.

Holleman and Stephenson (1981) examine skeletal muscles of wolves collected from predator control programs administered by Alaska's Department of Fish and Game. The study uses the radiocesium concentration method, which depends upon the accumulation of fallout radiocesium. In simpler terms, researchers can identify what prey species wolves are eating since the concentration of radiocesium in wolf muscle depends on the intake and absorption from food sources. The radiocesium body burden of each wolf is calculated from the concentration of skeletal muscles. It is assumed each wolf's body weight consists of 43% skeletal muscle and that 80% of the radiocesium body burden is in the skeletal muscle. The study focuses on eight areas, all of which have different compositions of moose, caribou, black-tailed deer, Dall sheep, fish, and small game species. Skeletons with high concentrations of radiocesium suggest caribou comprised the majority of the wolf's diet, while skeletons with low concentrations suggest moose were relied upon more heavily. The results of this study support the idea that wolves are strongly dependent on ungulate species as prey. In areas where several ungulates are available, wolves often favor one species to another. For example, in areas of several abundant species, caribou seem to be the preferred prey species due to the fact wolves feed on them almost exclusively. In areas where prey species are scarce prey selection is merely a function of availability.

3.2 Predator-Prey Behavioral Studies

It is clear that predators have multiple effects on prey populations, ranging from density dependence to feeding characteristics. All literature analyzing behavioral responses demonstrate that prey will alter habits in one way or another in the presence of predators. Differences in behavior will not only depend on the type of predation faced, but the topological environment, and prey densities in that area. These behavioral responses may also be a result of genealogical experimentation looking for a loophole to allow more animals the chance to reproduce and further the population of a species.

Studies using mathematical modeling focus on how predators and prey adjust to changing populations of other species. Both Sih et al. (2000) and Preisser et al. (2005) find trait-mediated effects to be larger than direct consumption. Preisser et al. conducts a meta-analysis of literature to assess the magnitude of both trait-mediated and density mediated interactions. These studies characterize trait mediated effects to be at least as large as direct consumption (63% and 51%) and even larger when taking into account predators' effects on preys' resources (85%). Anti-predator behavior carries costs to prey in the form of reduced energy income, lower mating success, and increased vulnerability to other predators. Similar studies by Sih et al. (1998) and Lima (2002) conclude active searching predators focus on high densities of prey. This relates to increases in prey movement and dispersal, increasing the predation risk from ambush predators. Differences in these studies are mostly due to assumptions on their respective models.

Creel et al. (2005) study the Gallatin drainage in the Greater Yellowstone Ecosystem of Montana. Based upon aerial counts conducted by MFWP, the elk within this area have ranged from 1,214 to 3,028 since 1927. Since wolves have recolonized the area, in seven out of eight winters the population has been below 1,650 elk. Five of these winter counts were the lowest on record to date.

In order to gain a better understanding of elk movements with the presence of wolves, researchers attached GPS units with data loggers to radio collars and fit them to 14 elk over a two year period. Wolf presence in the drainage is also determined through radio telemetry. Wolf tracks and scat are additional signs used to determine wolf presence. Through the use of spatially and temporally fine-scaled GPS data, the authors find elk respond to wolf presence on a time scale of one day and a spatial scale of 1 km or less. They also conclude elk occupy foraging sites in open grasslands when wolves are absent, but shift to coniferous cover in the presence of wolves. This shift is similar to elk responses due to human hunters, implying when the risk of predation increases, elk adjust their behavior.

According to Creel et al. (2007) the majority of wolf-elk analysis has lacked focus on potential anti-predator behavior dynamics. Elk respond to wolf presence in various ways such as increasing vigilance, and changing foraging and habitat selection. Female elk produce stronger anti-predator behavior than males and fall victim to wolves far less often. The authors use enzyme-linked immunosorbent assay (ELISA) to assess the reproductive physiology of elk throughout five winter ranges in the Greater Yellowstone Area. Mean fecal progesterone is measured and is found to be correlated with elk to wolf ratios. Areas with heavy predation see low progesterone values while areas with low predation see high progesterone values. For example, the lowest progesterone concentration is associated with a ratio of 8 calves per 100 cows. The highest concentration has calf cow ratios above 30. The results of this study show anti-predator behavior carry costs that can alter reproductive physiology and demography. If consideration is not given to the indirect effects researchers may be over estimating the direct predation effect in the elk-wolf system.

Many models use risk as a fixed property where prey have perfect knowledge of the predation risk. Lima (2002) is one study which models risk as a variable commodity to which prey must adjust. Lima discusses how predators are treated as a source of risk rather than a participant in a much larger behavioral world. The author finds that when predators are allowed to strategically respond to prey behavior the expectations of prey behavior changes. While this paper uses predator-prey games of patch and habitat choice to study these effects, the author notes empirical analysis lacks this type of framework. New studies may benefit from implementing variable risk, since currently; studies may be underestimating the true behavioral responses of prey.

It is clear that behavior is a key element of predator-prey relationships. Insight is gained into how species will adjust as well as how the environment is affected by these responses. Predators shape both prey populations and the environment through trait-mediated effects. Prey dispersal due to predators helps to combat overgrazing which has a direct impact on the health of game species and the livestock industry.

3.3 Studies on Predator-Prey Models

The papers in this section review the dynamics of predator and prey species. Much of this research starts with a Lotka-Volterra model of population dynamics. These models consist of a set of first order, nonlinear, differential equations used to describe how species interact. It is widely accepted that oscillating populations are a part of predator and prey systems. This research helps to highlight factors that cause systems to converge or diverge from steady state equilibriums. The inherent problem with this research is that many lack real world data; instead they are based on mathematical models with simulated data. The upside of these models is that researchers can get a better understanding of what parameter values push a population towards equilibrium.

One occurrence often noted in predator-prey models is when predator populations begin to rise; prey populations will be reduced, leading to oscillatory paths. Baalen et al. (2001) study a Lotka-Volterra model with the simple assumption that alternative food sources have a fixed density. Through this analysis it is found that when a prey population drops below a threshold density, optimal foraging predators switch to alternative food. This may be accomplished in two ways: either by including the alternative food in their diet or by moving to alternative food sources. They find that these responses lead to unstable equilibriums. In terms of oscillations, this switch may prevent unbounded oscillations, but promote persistence. The reason being, is as predators switch to alternative food, primary prey have a chance to repopulate. Once the prey populations' reach sufficient numbers, predators will switch back until once again the prey has been depleted.

Contrary to these results, Arditi et al. (1991) conclude systems that possess adaptive predators are locally stable and systems possessing specialist predators are unstable. Here a ratio-dependent predator-prey model is used that assumes the functional response is equivalent to the predator-prey ratio. This simple assumption gives the model radically different properties than the traditional prey-dependent version. Mainly, an increase in primary production leads to a proportional increase in the equilibrium of all species. In ecological terms, the increase of biomass at the smallest level trickles down to the largest carnivores, increasing populations all the way through.

Beddington et al. (1976) also model predator-prey using difference equations. The model is guided by three elementary observations. First, the populations of species fluctuate around characteristic mean levels of abundance. Secondly, the amplitude of fluctuations around equilibria is different for individual species, and thirdly, populations will occasionally become extinct. Through these assumptions it is concluded deterministic models have a system that becomes constant at some point in time. Non-deterministic models have one or both populations becoming extinct. Therefore, the idea of persistence is not supported in the non-deterministic world.

Types of predators can also have an impact on the prey population within the environment. Hassell and May (1986) support the idea that specialist predators are able to invade and co-exist more easily then generalist predators. Their study focuses on the dynamics of a predator-prey, or parasitoid-host systems, where either the predator or the parasitoid is a generalist, whose population is buffered against changing prey populations. The study is broadened to include a specialist natural predator. In certain cases specialist predators are found to increase prey populations more significantly than generalists. The specialist predator is a natural enemy of the generalist; it competes with the generalist and reduces its population. Through these interactions the risk of predation is reduced to the prey population.

A similar study by Fryxell and Lundberg (1994) compare the dynamics of predator-prey systems with both specialist and adaptive generalist predators. A Lotka-Volterra model is used for a two-prey system, where the two populations do not interact except through mediated effects by a common predator. The rules of this model are first; the predator always attacks species 1, since it is the more profitable prey. The probability of attack of species 2 is dictated by an energy-maximizing decision rule. This rule applies solely to the adaptive predator since predation of species 2 by the selective predator is set to zero. The results find adaptive predators should feed exclusively on the most profitable prey until the expected rate of energy gain is equal to the profitability of the less profitable prey. Hence, it is determined patterns of partial prey preference are more stabilizing than perfect optimal diet selection.

In a study by Choi (1997) a biological population and Lotka-Volterra model are applied to organizations and social systems. The paper aims to demonstrate how merging system dynamics along with population ecology helps to assess the sensitivity of initial conditions. By using simulations with Ithink software, dynamical properties of the Lotka-Volterra model are made. Though chaos is rare in the Lotka-Volterra type models, where per capita growth rates are a linear function of population density, this process allowed Choi to conclude otherwise. An example of this would be when there are three competing species where species 1, has a direct negative effect on each of the other two species. Species 1 also has a positive effect on species 2 by competing with competitor 3, and benefits species 3 by competing with species 2. In this instance it is possible for a population increase in species 1 to increase the equilibrium density of species 3. This is reliant on the indirect effect being larger than the direct one.

3.4 Studies of Wolf Impacts on Industry

The dynamics of predator-prey models are determined by factors affecting both predators and prey. These factors have far reaching effects that not only affect the environment in which these animals live, but many industries as well. According to Defenders of Wildlife (as cited in Duffield et al. 2006), since 1996, payments for wolf depredation on livestock have averaged $27,000 per year. In 2004 and 2005 these payments increased to an average of $63,818. These numbers may be understated since many depredations go unreported, therefore the true impact may be well above these estimates. The reintroduction of wolves has also impacted the market for big game hunts. In 1994, the reduced hunter harvest of elk, mule deer, and moose in the GYA was estimated to result in foregone hunter permit benefits ranging from $187,000 to $465,000 per year. Specifically, the elk industry has estimated annual losses of approximately $97,000, or 50% of the total value of foregone hunting opportunities. Thus, changes in ecological systems can greatly impact the economy of the surrounding communities (USFWS Final EIS, 1994; as cited in Duffield et al. 2006).

Prior to wolf reintroduction preliminary estimates were produced regarding the impact wolves have on game populations. For instance, the Final Environmental Impact Statement produced by the U.S. Fish and Wildlife Service (USFWS) in 1994, estimates the prospective impact of recovered wolves in Yellowstone and Central Idaho. In the Yellowstone area recovered wolves are estimated to kill on average 19 cattle, 68 sheep, and approximately 1,200 ungulates every year. In addition, the report claims a recovered wolf population will not affect hunter harvest of male ungulates, but may reduce the harvest of female ungulates such as elk, deer, and moose. Elk populations are estimated to reduce by 5%-30% (30% attributed to small herds), deer by 3%-19%, moose by 7%-13%, and bison by 15% with the reintroduction of wolves. Human harvest of bighorn sheep, mountain goats, and antelope are not expected to change. In Central Idaho a recovered wolf population is estimated to kill approximately 10 cattle, 57 sheep, and up to 1,650 ungulates each year. Once again hunter harvest of female elk is estimated to reduce by 10%-15%, but the harvest of bull elk is not expected to be effected. Contrary to the Yellowstone Area, in Central Idaho the harvest of deer, moose, bighorn sheep, and mountain goats by humans is not expected to be impacted (USFWS Final EIS, 1994).

In 1992, Frisina conducted a study to look at the competition between wildlife and domestic livestock on wildlife ranges. The goal of the study was to design a grazing system, which would resolve conflicts between domestic livestock and wildlife on summer ranges, with emphasis on providing high quality resources to herds of elk. The study encompassed a 9,500 acre area southeast of Anaconda, MT. Pastures received one of three grazing treatments. Treatment A was classified as available to livestock throughout the entire grazing season, as well as free ranging wildlife. Treatment B was classified as available to livestock and wildlife only after seedripe. While treatment C was a grazing area which was restricted to livestock, but allowed for free ranging wildlife. The study found 94% of the observed elk populations were in pastures unoccupied by cattle. The preference of elk for habitats not occupied by cattle appeared to be related to intensive removal of vegetation by the cattle, rather than a social intolerance of cattle.

In a study by Miller (1982) probability of participation equations are used to analyze the effect elk herd specific changes have on hunter participation. Through telephone and mail surveys the researchers were able to gather information on hunter activity throughout the state of Washington. The authors find that as elk populations decrease, hunter days will also decrease. For example, say the elk population decreases by ten percent. This reduction would result in a loss of 49,900 days due to discouraged hunters and a loss of 27,982 days from less hunting. Therefore reductions in elk herds will impact hunting not only through fewer licenses being distributed but through discouragement of hunters in general.

Batastini and Buschena (2007) use measures of game agency response, hunter demand, and hunter success to measure how recreational users adjust their behavior when new factors impact the population of resources. The study finds negative effects of reintroduced wolves on hunting permits. Reintroduced wolves are classified as wolves transported to Yellowstone National Park during the mid-1990s. These packs have since migrated outside the park, therefore, impacting recreational users. Interestingly, the study did not find significant effects of naturally occurring wolves. One shortcoming of this study is that data is limited. Montana Fish, Wildlife, and Parks withheld the release of hunting reports from the years 1996-1998; these years are the beginning of wolf reintroduction.

DATA

This chapter will familiarize the reader with methods used to construct the variables used in the empirical models. A description of where this data was gathered as well as how it was used will be provided.

4.1 Hunter Harvest Surveys

Each year following the hunting season MFWP conducts telephone surveys to gather hunting and harvest information. The telephone interviews take place mid-week, evenings, and weekends in order to speak to hunters one-on-one. This allows MFWP to get the most accurate information possible regarding license type, species, sex, and location of kills. Results from these surveys are then used by wildlife managers to evaluate permit quotas, season dates, and future regulations. The variables are classified by hunting district and further subdivided by hunting licenses (MFWP Hunter Harvest Surveys, various years).

The hunter and harvest variables by species include; hunting districts, the number of permits issued, hunters, residency of hunters, total harvest, males, females, young, management success, time of harvest, weapons use, and size of males taken (MFWP, Hunting Harvest Surveys, various years/species). The data for elk ranges from 1999-2010. For the purpose of this paper only the sum of all licenses will be used due to variation in license type throughout the data.

4.2 Drawing Statistics

The drawing statistics were collected from MFWP. They are useful to this paper since hunting district quotas give information on the population of animals within each district as well as the district specific management goals. Drawing statistics are a helpful tool used by hunters when choosing which district or license to apply for. The species-specific statistics give an overview of the odds of drawing different licenses throughout the state. They are broken down further to reflect landowner preference, the nonresident limit of ten percent, and 1st, 2nd, and 3rd choice applicants (MFWP Drawing Statistics, 2011).

4.3 Wolf Data

The wolf data used in the empirical estimations of this thesis were compiled from two sources; MFWP provided a shapefile consisting of pack locations from 1999 through 2010, and wolf pack populations were compiled from USFWS annual reports. The shapefile included pack locations by year, pack name, and the area each pack was located. The annual reports include the general region of each pack, and size throughout Montana, Idaho, and the Greater Yellowstone Area (USFWS Annual Reports, various years).

In order to make this data usable for analysis, shapefiles were first converted to longitudes and latitudes. Wolf pack locations were then used to compute the distance each pack was located from individual hunting units. Next, population data was merged with wolf distances. Lastly, wolf populations within 100, 50, 37.5 and 25 miles were computed to determine which districts were inhabited by wolves each year. While wolves were living within Montana prior to 1999, no such data was available for pack size or location during this time period.

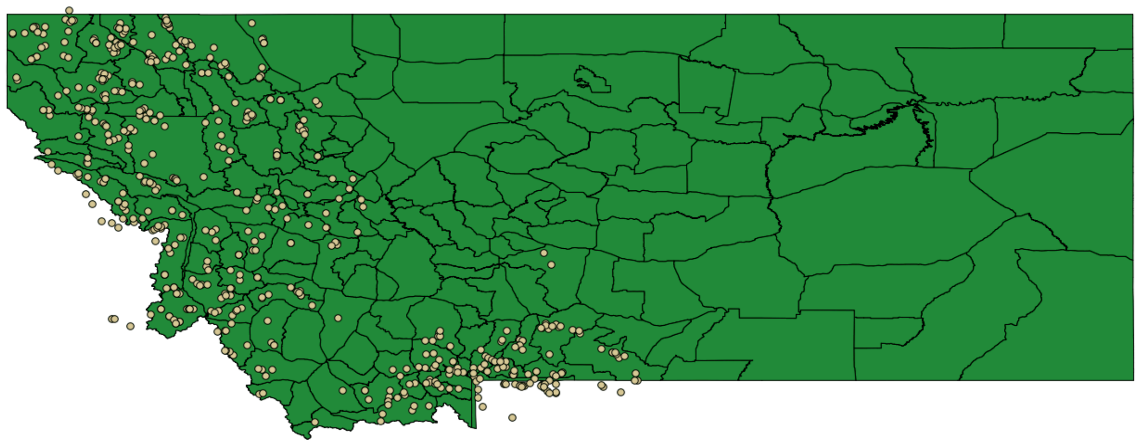


Figure 4.1 Montana Hunting Districts with Wolf Locations (1999-2009)

4.4 Weather Data

The weather data was obtained from the National Climate Data Center (NCDC) and the Global Historical Climatology Network (GHCN). The data ranged from 1970-2010, and includes temperature and precipitation for weather stations around the state of Montana (Atwood, 2011). By averaging the five closest weather stations to each hunting district, average yearly and monthly temperatures and precipitation were computed. Then by using daily average of observations for temperature and precipitation, deviations from monthly averages were found. Therefore the weather variables measure deviation from long-term trends.

Heating degree days[1] were used to measure how severe days were below 32 degrees Fahrenheit as well as the accumulation over time. These proxies allowed us to gauge the energy animals expend to maintain a constant body heat. For example if the average temperature on a given day was zero degrees, the heating degree days on the given day would equal 32 units. If daily average temperatures were zero for 10 consecutive days, the result would be 320 accumulated heating degree units. Any day that was above 32 degrees would have a heating degree day value of zero.

4.5 Trophy Game Data

Record information of trophy game animals throughout North America are recorded by two clubs; The Boone and Crockett Club (BCC) and the Pope and Young Club (PYC). The difference between the two is that BCC records animals taken with firearms while PYC records animals taken by bow and arrow only. Data on the number of bull elk taken between the years 1999-2010 were gathered from each club's game records. The data contains the score, county, and date of harvest (Boone and Crockett Club, 2011; The Pope and Young Club, 2011). The location data was combined with hunting district boundaries to determine where animals were taken. Data was also recorded for the number of animals taken within each district and the mean score of those animals.

[1] Note: Heating degree days as defined in this document are not the same as heating degree days used to reflect the demand for energy needed to heat a building. Housing HDD's use 60 degrees Fahrenheit as a base temperature; here we use 32 degrees Fahrenheit.

4.6 Yellowstone/Canada Distance

Lastly, the distance from Yellowstone National Park and the Canadian border were computed for each hunting district. The Canadian border shape file was gathered from the Tiger Data website and the Yellowstone shape file was downloaded from the Wyoming State Geological Survey website. The distance was computed by taking the closest point of each hunting district to the border of either Yellowstone or Canada. Districts were than given a band denoting whether they were within 25, 50, etc. miles from each location. This data was finally merged with the rest to complete the dataset used in this empirical analysis.

4.7 Variable Description

Hunter harvest statistics throughout Montana is the primary data used in this study. Tables 4.1-4.3 include the composition of animals taken, hunter applications, mean trophy scores, and weather by month and year. Average wolf populations are included to give readers an idea of their influence by region.

Each region of Montana has a unique composition of game and hunters. By analyzing the characteristics of each area we can get an idea of what our empirical analysis may tell us. Clearly shown in the summary statistics, southwest Montana is a premier destination for elk hunters. The area boasts the highest number of elk taken, largest trophy game, and the most hunter applications. Surprisingly, with its close proximity to YNP, the average wolf population is the lowest when compared to the west central and northwest portions of the state. The west central portion of the state has a higher wolf population and approximately 38% less elk harvested each year compared to the southern portion. Northern Montana has the lowest elk harvest with the highest population of wolves.

The weather variables have already been rescaled to reflect the change from monthly and yearly heating degree-days and precipitation. During the last decade, the time period used for this analysis, yearly precipitation has differed throughout regions of Montana. Southwest Montana averages 9.95 inches per year, west central 11.1 inches, and northwest 14.47 inches. During November when snowfall can have a major impact on elk harvest all areas of the state have had lower average snowfalls. In the southwest and west central portions of Montana temperatures have been colder, denoted with an increase in heating degree days, while the northwest portion has averaged fewer heating degree days. Higher snowfall throughout the year may decrease game populations. This effect combined with less precipitation in November that drives elk to lower elevations, may adversely affect the harvest of Montana’s hunters through less game taken, and lower quotas due to decreases in elk population.

Table 4.1 Southwest MT Variable Description

	Obs	Mean	Median	Std.Dev	Min	Max
HD	472	335.03	327	25.94	300	393
Year	472	2005.06	2005	3.17	2000	2010
$Harvest_{(t-1)}$	472	269.97	233.5	182	6	1335
Wolf pop	472	20.44	13	21.49	0	105
Wolf $pop_{(t-1)}$	472	18.31	11	20.93	0	105
City distance	472	42.11	37.02	24.07	3.83	101.86
Mean Trophy $Score_{(t-1)}$	467	311.21	310.04	16.21	278.31	373.2
Quota	318	1446.3	322.5	9702.57	0	100349
Hunter Apps.	318	763.86	336	1438.63	2	11167
Drawing $Success_{(t-1)}$	338	422.38	325	378.4	0	3050
Drawing $Surplus_{(t-1)}$	338	48.73	0	532.8	0	9745
Yearly Prcp	472	9.95	9.72	2.56	4.88	18.34
Yearly HDD’s	472	1170.56	1137.45	281.74	633.51	2261.57
Change in Jan Prcp	472	-0.59	-0.93	2.91	-12.18	13.72
Change in Feb Prcp	472	-0.07	-1.01	3.27	-9.37	15.76
Change in Feb HDD’s	472	-3.71	-11.56	78.32	-196.16	175.82
Change in Mar Prcp	472	-1.23	-1.81	3.75	-11.03	12.45
Change in April HDD’s	472	-3.42	-9.21	21.83	-53.72	124.03
Change in Nov Prcp	472	-0.22	-1.05	4.36	-11.46	19.04
Change in Nov HDD’s	472	2.14	-25.15	95.15	-148.6	276.1
Yearly $Prcp._{(t-1)}$	472	9.68	9.38	2.56	4.88	18.34
Change in Apr $Prcp_{(t-1)}$	472	0.88	0	5.45	-9.17	16.96
Change in Apr HDD’$s_{(t-1)}$	472	-2.7	-8.69	21.6	-53.72	124.03
Change in May $Prcp_{(t-1)}$	472	-1.74	-1.98	7.47	-20.36	19.35
Change in Oct HDD’$s_{(t-1)}$	472	2.75	-10.58	24.98	-29.37	71.7
Change in Nov $Prcp_{(t-1)}$	472	-1.18	-1.89	3.6	-11.46	11.83
Change in Dec $Prcp_{t-1)}$	472	-0.37	-0.95	3.05	-8.17	10.52
Change in Dec HDD’$s_{(t-1)}$	472	-13.73	-31.47	121.88	-217.85	286.27
Distance to YNP	472	65.88	65.85	36.34	4.49	131.03
Band to YNP	472	3.21	3	1.51	1	6

Table 4.2 West Central MT Variable Description

	Obs	Mean	Median	Std.Dev	Min	Max
HD	299	246.43	250	36.09	200	298
Year	299	2005.03	2005	3.18	2000	2010
$Harvest_{(t-1)}$	299	167.06	136	136.98	0	952
Wolf pop	299	26.9	19	23.4	0	105
Wolf $pop_{(t-1)}$	299	22.17	16	20.58	0	93
City distance	299	38.04	36.21	15.84	13.44	78.58
Mean Trophy $Score_{(t-1)}$	291	307	306.16	12.2	281.56	351.06
Quota	269	232.55	200	160.47	5	703
Hunter Apps.	269	311.56	301	202.87	8	1259
Drawing $Success_{(t-1)}$	270	234.94	200	160.24	5	825
Drawing $Surplus_{(t-1)}$	270	9.41	0	28.09	0	227
Yearly Prcp	299	11.1	10.83	2.4	6.44	29.21
Yearly HDD’s	299	925.75	925.61	246.81	382.75	1443.58
Change in Jan Prcp	299	-1.64	-2.09	4.94	-16.51	19.2
Change in Feb Prcp	299	-0.46	-1.19	5.14	-15.52	18.42
Change in Feb HDD’s	299	-13.06	-34.24	68.56	-126.1	199.68
Change in Mar Prcp	299	0.67	-0.36	4.81	-7.75	18.64
Change in Apr HDD’s	299	0.39	-1.78	12.94	-20.52	61.84
Change in Nov Prcp	299	-0.19	-0.93	7.55	-15.99	68.87
Change in Nov HDD’s	299	4.31	-5.05	79.82	-120.85	224.49
Yearly $Prcp_{(t-1)}$	299	10.79	10.54	2.41	6.16	29.21
Change in Apr $Prcp_{(t-1)}$	299	-0.23	-1.77	5.75	-9.66	15.88
Change in Apr HDD’$s_{(t-1)}$	299	0.8	-1.38	12.86	-20.52	61.84
Change in May $Prcp_{(t-1)}$	299	-1.58	-2.88	7.44	-14.15	27.61
Change in Oct HDD’$s_{(t-1)}$	299	4.6	-5.27	22.72	-19.55	78.73
Change in Nov $Prcp_{(t-1)}$	299	-0.56	-1.13	7.33	-15.99	68.87
Change in Dec $Prcp_{(t-1)}$	299	-1.62	-2.26	4.32	-17.3	24.11
Change in Dec HDD’$s_{(t-1)}$	299	-15.8	-35.89	117.83	-199.22	260

Table 4.3 Northwest MT Variable Description

	Obs	Mean	Median	Std.Dev	Min	Max
HD	207	123.99	122	19.34	100	170
Year	207	2005.04	2005	3.15	2000	2010
$\text{Harvest}_{(t-1)}$	207	77.45	60	79.78	3	491
Wolf pop	207	35.66	30	23.3	3	110
$\text{Wolf pop}_{(t-1)}$	207	30.45	25	21.49	0	110
City distance	207	43.41	47.27	19.2	4.57	70.11
$\text{Mean Trophy Score}_{(t-1)}$	195	306.43	302.25	22.9	262.67	375.88
Quota	143	75.38	35	117.68	5	805
Hunter Apps.	143	236.21	164	221.26	14	984
$\text{Drawing Success}_{(t-1)}$	141	77.94	50	117.75	5	805
$\text{Drawing Surplus}_{(t-1)}$	141	0	0	0	0	0
Yearly Prcp	207	14.47	13.9	3.42	8.22	31.29
Yearly HDD’s	207	778.29	777.1	228.26	313.83	1467.61
Change in Jan Prcp	207	-0.42	-1.41	7.99	-20.66	22.87
Change in Feb Prcp	207	-2.34	-1.33	6.23	-19.96	17.05
Change in Feb HDD’s	207	-12.65	-26.95	64.2	-138.7	161.9
Change in Mar Prcp	207	0.41	-1	6.07	-13.4	19.7
Change in Apr HDD’s	207	1	-0.58	7.38	-16.54	35.66
Change in Nov Prcp	207	-2.61	-4.83	10.47	-21.31	67.03
Change in Nov HDD’s	207	-0.45	-4.94	65.42	-115.62	138.41
$\text{Yearly Prcp}_{(t-1)}$	207	14.11	13.51	3.26	8.22	31.29
$\text{Change in Apr Prcp}_{(t-1)}$	207	-1.21	-1.52	4.89	-14.19	13.09
$\text{Change in Apr HDD's}_{(t-1)}$	207	1.09	-0.58	7.36	-16.54	35.66
$\text{Change in May Prcp}_{t-1)}$	207	-3.22	-4.72	6.79	-15.14	27.17
$\text{Change in Oct HDD's}_{(t-1)}$	207	4.26	-4.67	18.44	-17.79	65.32
$\text{Change in Nov Prcp}_{(t-1)}$	207	-2.69	-4.83	10.39	-21.31	67.03
$\text{Change in Dec Prcp}_{(t-1)}$	207	-1.81	-2.3	5.62	-19.15	22.15
$\text{Change in Dec HDD's}_{(t-1)}$	207	-9.15	-20.45	124.03	-230.23	245.44
Distance to Canada	207	61.93	62.04	28.69	8.6	107.29
Band to Canada	207	3.02	3	1.29	1	5

MODELS

5.1 Hunting Permits

Montana hunting licenses can be categorized as having two main attributes, their regulations and their hunting characteristics. Each license has regulations that holders must follow when harvesting game. For elk the three types of licenses available are the general license, the B license, and the permit license. The general elk license is valid for one elk and can be used for elk as indicated under the "General Elk License" heading on the deer and elk hunting district pages. Hunters are only allowed one general elk license.

Table 5.1 Montana Elk Hunting Licenses

License/Permit	**License Specifics**
Elk-General	Valid for one Elk. Hunters may hold only one general elk license
Elk B License	An Antlerless elk license valid during a specific time period and in a particular hunting district or group of districts. Elk B licenses are offered through drawings only.
Elk Permits	Permits must be used with a general elk license. These are not a secondary license and do not allow the holder to kill an additional animal. Rather, the permit expands the opportunity of hunters to hunt in a particular district and only allows the harvest of bull elk. Residents must hold a general elk license to apply and nonresidents must hold a big game or elk combination license to apply.

Source: Information obtained from MFWP, Montana Hunting Regulations, 2011

The elk B license is an antlerless license valid during specified time periods and in particular hunting districts. Lastly, an elk permit must be used with a specific hunting license (General License). Permits are not a second license; rather they allow hunters the opportunity to hunt species in a particular hunting district, expanding their options. Some elk B licenses and permits may be purchased over-the-counter while others must be obtained through drawings. Hunters may apply for permits that allow hunting in otherwise restricted areas or time periods (MFWP Hunting Regulations, 2011).

Due to the fact that there are more applicants than available permits, hunters who apply are not always selected. MFWP uses a bonus point system to provide applicants at least one opportunity at drawing a license while still giving those who failed in the past a chance to increase their odds. The bonus point system allows applicants to accumulate one bonus point for each unsuccessful year. Each point then becomes an extra chance in future drawings. For example, applicants have one chance to be drawn the first year they apply. If they are unsuccessful they would have two chances the second year and so on. Bonus points are accumulated independently for each species and only apply to first choice districts. Bonus point participation is voluntary and costs two dollars for residents and twenty dollars for nonresidents (MFWP Hunting Regulations, 2011).

The second set of attributes may be defined as the characteristics associated with each hunting district. MFWP provide hunting and harvest information for the previous year's hunting season. These reports include information on permits issued, the number of applicants, hunters, make-up of the harvest, dates of harvest, weapons use, number of animals harvested, size of male animals, and the success of harvesting. The dates of harvest are divided into early, regular, and late season and the size of each male animal is listed by points. The management success rate is defined as the total harvest divided by the number of licenses issued. The percent success is defined as the percent of all hunters that harvest an animal. Weapons use depicts whether a rifle or bow were used in the harvest. As stated above, this data is available to hunters, giving them an idea of the hunting characteristics associated with each hunting district (MFWP Hunter Harvest Surveys, various years).

While the hunting harvest reports define attributes associated with historical harvest, additional attributes include the landscape, ease of access, game quality, and the demographics associated with each hunting unit. Information on herd quality is available through the Boone and Crockett Club (BCC) and Pope and Young Club (PYC) record books. The information in these record books provides hunters with the score of animals taken within different counties throughout the state of Montana (Boone and Crockett Club, 2011; The Pope and Young Club, 2011).

Hunters place value on license type as well as different physical endowments associated with each license. Holding all else constant, one can expect applicants will place higher value on licenses associated with positive characteristics. For instance, one hunter may prefer to hunt in open expanses of national forest that have a history of trophy game. Another hunter may place value on the ease of access, hunting in areas within close proximity to their residence. As discussed by Nickerson (1990), changes in demand of permits may be attributed to changes in the characteristics of a permit. This happens when changes in permit characteristics alter the valuation individuals place on it. Increases in positive recreational benefits will increase demand while decreases in positive recreational benefits will have a negative effect, decreasing demand.

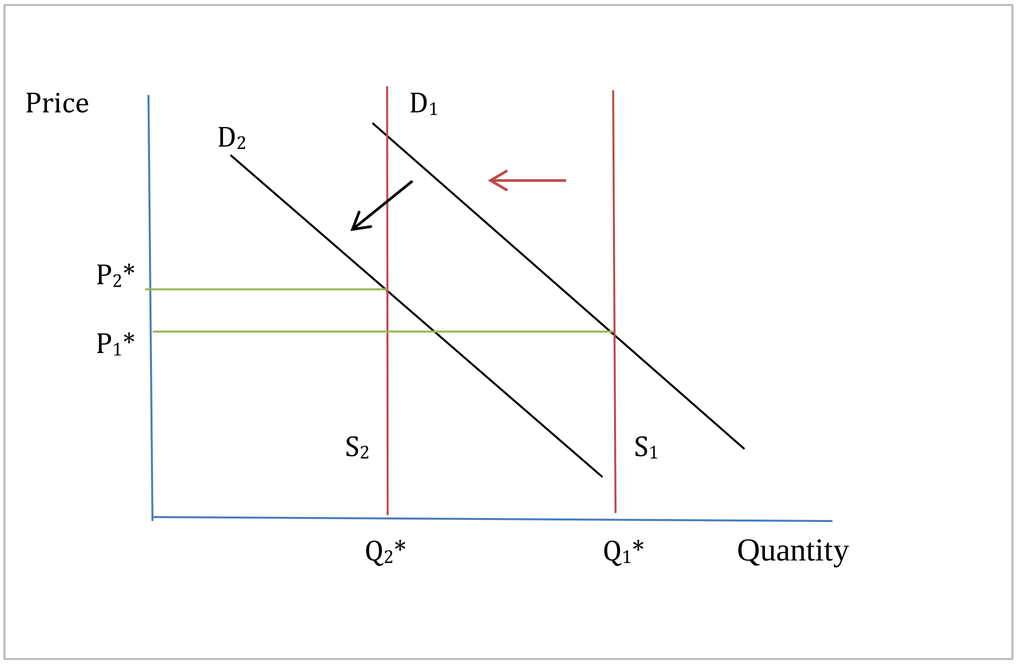
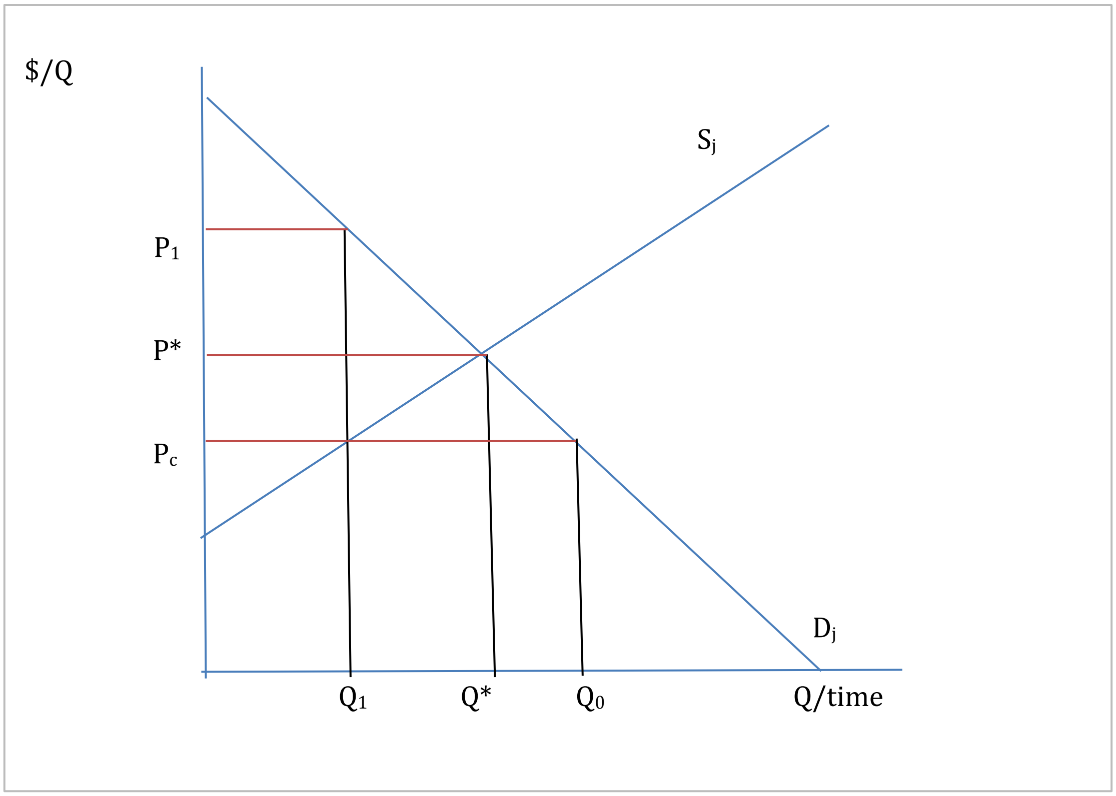


Figure 5.1 How Wolves Effect the Supply and Demand of Permits

An example of this is depicted in figure 5.1. Picture a situation where wolves enter a hunting district and start killing elk. Following Nickerson (1990), wolves are likely to be a negative characteristic, due to the fact that they decrease game. The presence of wolves may then be assumed to decrease the demand (Shift from D_1 to D_2). MFWP may also reduce the number of permits available, shifting supply from S_1 to S_2. If both of these scenarios happen one can expect the quantity of permits demanded within this district to shift from Q_1* to Q_2*. If the reduction in demand does not match the reduction in supply in a particular district, then the price of permits will increase by P_2*-P_1*. This is only one possible outcome of this situation, but the point is wolves are likely to negatively impact the supply and the demand of hunting permits throughout hunting districts in the state of Montana. It must also be noted that if demand decreases in one district it is likely to increase in another, possibly offsetting the effects seen above. Because of this, the overall effect of wolves on the Montana hunting industry cannot be determined. The problem in Montana is that the price of hunting licenses is fixed, meaning hunters must make up the difference of P_2*-P_1* through other means. The ways in which hunters will do this are discussed next.

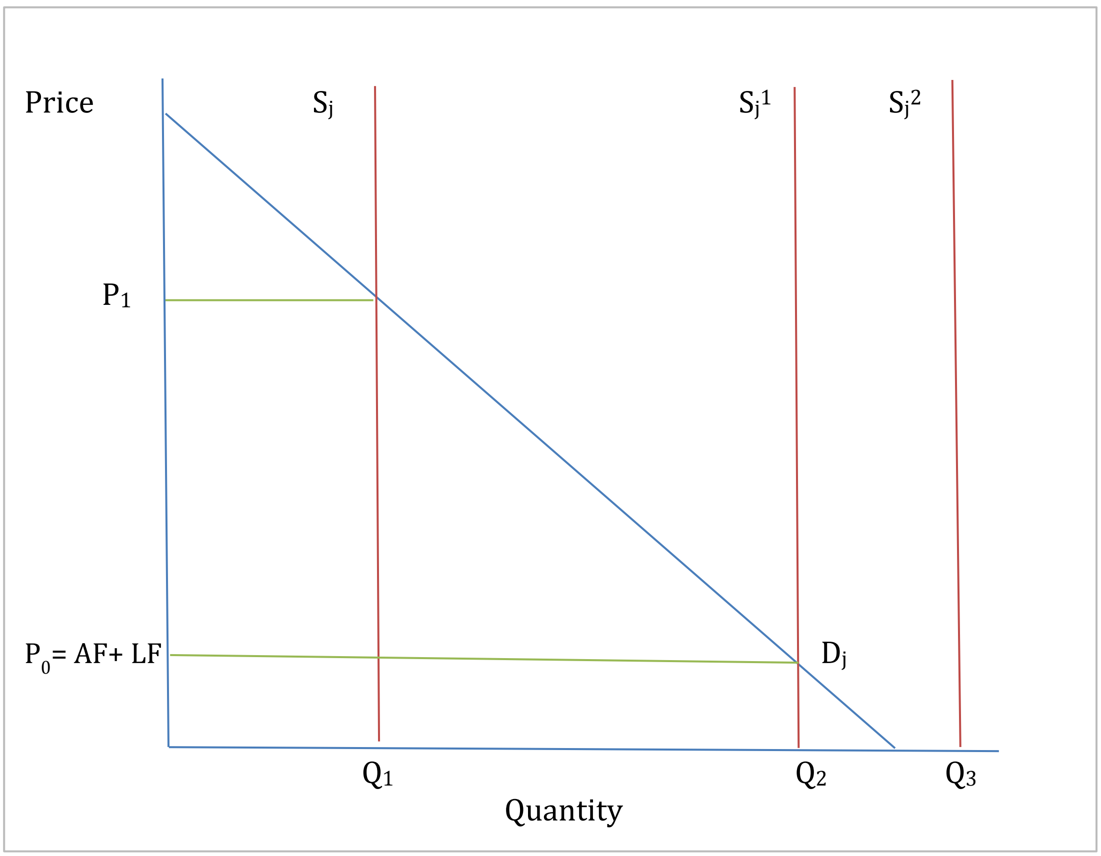
According to Barzel (1997), “In models of rationing by waiting, queuing is the means by which ownership is established.” Real-world price controls differ from rationing by waiting in two ways, first when using rationing by waiting, price is set to zero. In normal price control analysis the price is assumed to be lower than the equilibrium price. Second, in rationing by waiting it is assumed competition occurs through queuing, while in price control analysis this is only assumed initially. Consider figure 5.2, where D_j is the demand curve and S_j is the supply curve. The equilibrium price and quantity are P* and Q*. Assuming the control price P_c is perfectly enforced, a shortage will exist (Q_0-Q_1). Consumers demand Q_0, but sellers only supply Q_1. When sellers supply Q_1, consumers are willing to pay P_1. Since consumers can only pay P_c they will make up the difference between (P_1-P_c) by other means, such as waiting in line. The area (P_1-P_c)*Q_1 represents the dollar value of the time expenditure (Barzel, 1997).



Source: Obtained from Barzel (1997)

Figure 5.2 Rationing by Waiting: Supply and Demand of Hunting Licenses

Figure 5.3 depicts the situation hunters face when purchasing a license in the state of Montana through drawings rather than over-the-counter. The bonus point system/drawing mechanism uses rationing by waiting. MFWP uses biological studies to determine the supply of license j, fixing the quota level for each hunting unit prior to the season. Supply of license j is depicted in figure 5.3 by a vertical line (S_j, S_j^1, and S_j^2). Demand is depicted by D_j. Individuals who wish to enter the drawing must pay a non-refundable application fee (AF); they must then wait to be selected. If selected they pay the License fee (LF) to obtain the permit. If not selected they must wait another year to apply once again for a permit. The price of a license is represented by AF + LF = P_0. If the quota is set at Q_1 (Supply S_j) then the equilibrium price is P_1. Since the price of hunting licenses isn't allowed to adjust, P_0 represents the price consumers pay. Similar to figure 5.2, a shortage exists (Q_2-Q_1). Consumers will make up the difference between P_1 and P_0 through queuing. The monetary cost P_0 and the time cost (P_1-P_0). Equilibrium in this market occurs when the quota is set at Q_2 with a fixed price of P_0. A surplus may arise when the quota is set at Q_3 with a fixed price of P_0. The surplus is equal to the difference between the quantity supplied Q_3, and the quantity demanded Q_2 (Batastini and Buschena, 2007).



Source: Obtained from Batastini and Buschena (2007)

Figure 5.3 Supply and Demand of Montana Hunting Licenses

Since hunting permit prices are distributed at a below market value, most economic estimates depend on self-reported survey methods such as the travel cost or contingent valuation method to determine the true value of permits to consumers. These methods use the hunting experience (guides, lodging, food, etc.) to observe the actual value individuals place on permits. Buschena et al. (2001), provide an alternative approach when analyzing hunting permits in the state of Colorado. The authors rely on the fact that when goods are offered at below market prices, people must obtain them by competing at the margin. Much like Montana's system, Colorado hunting applicants compete by accumulating preference points that advance applicants chances of being drawn. The difference in Colorado is that applicants must submit a non-refundable processing fee along with the entire price of the permit that is refunded by the Colorado Department of Wildlife (CDW) if the applicant is unsuccessful. If unsuccessful, applicants are then awarded one preference point. Colorado's system also differs from Montana's since it allocates permits to the highest preference point bidder, while Montana applicants only increase their odds of success by obtaining bonus points. In Colorado's system, hunters purchase a permit in exchange for the license fee and the forgone interest of each accumulated preference point. Since the preference points come at a monetary cost, the authors are able to estimate how much the marginal applicant pays for each permit. The importance of this study is that it shows competition whether via price or queuing, gives valuable insight into consumers' willingness-to-pay.

5.2 Nickerson's Approach to Market Clearing under a Random Lottery

Nickerson (1990) analyzed the lottery of big game hunting in the State of Washington to estimate the demand for regulation by the state's game agency. In Montana the drawing program works a bit differently since applicants are able to apply for three districts while bonus points can only be used in first choice districts. The rules of this model have been altered to better represent the situation in Montana. Following Nickerson's approach the rules of this model are as follows: (1) supply of permits are fixed before drawings take place, (2) entry for first choice districts are a factor of bonus points, (3) entry for second and third choice districts are limited to one per person, (4) once applicants are drawn they cannot receive a second license for the same species, (5) permits are non-transferable. Following Nickerson (1990) the value of j (V_j) is the amount of money an individual would be willing to pay for the permit. V_j is a function of income (Y), prices (P), household characteristics (H), and permit characteristics (q). The supply of permit j is S_j, and the number of entrants into the drawing is $N_{j.}$ Therefore $(S_j/N_j)B$ equals the probability an individual acquires their first choice permit, where B denotes an individual's bonus points. (S_j/N_j) represents the probability an individual acquires their second or third choice permit. For ease of notation let $(S_j/N_j)B$ equal C_j, and (S_j/N_j) equal O_j. Lastly, P_L represents the non-refundable drawing entry fee.

The expected value of entering the lottery and drawing permit j can be denoted as $C_j^1(V_j^1-P_L)+O_j^2(V_j^2-P_L)+O_j^3(V_j^3-P_L)$, while the expected value of entering but not being drawn can be denoted as $-[(1-C_j^1)P_L+(1-O_j^2)P_L+(1-O_j^3)]$. The expected value of entering the lottery for permit j can be written as the sum of the expected values of its outcomes:

(4) $E(L_j) = [C_j^1(V_j^1-P_L)+O_j^2(V_j^2-P_L)+O_j^3(V_j^3-P_L)]–[(1-C_j^1)P_L+(1-O_j^2)P_L+(1-O_j^3)]$

where $j = 1$ to n

(5) $E(L_j) = C_j^1(V_j^1-P_L)+O_j^2(V_j^2-P_L)+O_j^3(V_j^3-P_L) \geq 0$

As depicted in equation 5 an individual who is risk-neutral will only enter a drawing if the expected value of entering the drawing is greater than or equal to zero (Nickerson, 1990).

5.3 General Model

Now that MFWP has taken responsibility of wolf management the agency must determine how to manage this population while taking into account the impact wolves have on activities such as hunting. When discussing the hunting industry a system of equations may be derived from the full biological and ecological model, to explain the relationship between wolves (W), game populations (P), hunters (K), and the total harvest (H). In this model it is assumed harvest in period *t* (H_t) is a function of game population (P_t), the number of hunters (K_t), as well as the number of wolves (W_t). The game population (P_t) is a function of wolves (W_t), and hunters (K_t). The number of Hunters (K_t) is written as a function of population (P_t), wolves (W_t), and hunter success (S_t) which is equivalent to (H_t/K_t). Lastly, wolves (W_t) are a function of the game populations (P_t). Denoted below are the four equations, the exogenous variables such as weather, trophy game, distance to Yellowstone etc. are denoted by $X_1 \ldots X_n$.

(6) Harvest $=H_t(P_t, K_t, W_t; X_1 \ldots X_n)$

Population$=P_t(W_t, K_t; X_1 \ldots X_n)$

Hunters $= K_t(P_t, W_t, S_t; X_1....X_n)$

Wolves $=W_t(P_t; X_1....X_n)$

5.4 Simplified Model

Although the realistic system presented above is physically accurate, predictions are not forthcoming. Therefore, a simplified version of this model will be used. For this model only wolf population dynamics will be modeled, insufficient information was available to model elk population dynamics. This reduces the model down to a three equation system: harvest (H_t), hunters (K_t), and wolves (W_t). Now the harvest function (H_t) is written as a function of hunters (K_t) and wolves (W_t). The number of hunters (K_t) is written as a function of wolves (W_t).

(7) Harvest $= H = f(K, W; X_1......X_n)$

Hunters $= K = F(W; X_1......X_n)$

Wolves $= W = g(X_1......X_n)$

In order to derive comparative statics from this system the model must be approached from an equilibrium point of view. First, the total derivative of each equation must be taken and rewritten in equilibrium. Then using the Implicit Function Theorem and Cramer's rule, comparative statics with respect to how the endogenous variables affect the exogenous can be derived. Rearranging each equation and setting the equations equal to zero is shown in equation (8). Differentiating these equations with respect to the endogenous variables is denoted in matrix notation (9) and in equation (10) the determinant $|Y|$ is calculated as being greater than zero.

(8) $H - f(K, W; X_1......X_n)= 0$

$K - F(W; X_1 \ldots\ldots X_n) = 0$

$W - g(X_1 \ldots\ldots X_n) = 0$

(9)

$$\begin{bmatrix} 1 & -\frac{df}{dK} & -\frac{df}{dW} \\ 0 & 1 & -\frac{dF}{dW} \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} dH \\ dK \\ dW \end{bmatrix} = \begin{bmatrix} f_{\vec{x}} \\ F_{\vec{x}} \\ g_{\vec{x}} \end{bmatrix}$$

(10) $|Y| = 1 > 0$

In order to sign the comparative statics the derivatives in matrix (9) must first be signed. The remainder of this section will discuss the expected values of these derivatives as well as the expected signs of the endogenous variables with respected to the exogenous.

As the number of hunters increase, the number of elk harvested in year *t* should also increase. While the overall success of hunters may decrease due to an increase in competition, harvest should increase. This assumption is also based on the fact that MFWP is unlikely to issue a higher number of permits in areas with high hunter demand since their goal is to manage game, making the sign of $\frac{df}{dk}$ positive.

Wolves are assumed to impact the level of harvest since wolves prey on elk. The higher the wolf population within a district the fewer elk present within that area. As noted previously, when wolves are present, elk break up into smaller herds and occupy protective cover. These distributional effects are likely to affect hunter harvest in various ways, the true effect being unknown. Due to this reasoning an increase in the wolf population reduces the level of harvest, $\frac{df}{dw}$ is assumed to be negative. Hunters are likely to adjust to the knowledge that wolves decrease the number of the elk. As a district's wolf population increases, hunters may choose not to hunt or may choose to move to areas with fewer wolves, the sign of $\frac{dF}{dw}$ is assumed to be negative.

The next step in our comparative static analysis is to differentiate the endogenous variables with respect to the exogenous variables of interest. Then using Cramer's Rule, signs may be determined. Important exogenous variables are trophy game (X_1), elk populations (X_2), November snowfall (X_3), November heating degree days (X_4), the distance to Yellowstone National Park (X_5), and the distance to Canada (X_6).

The number of trophy game is likely to affect the demand for hunting throughout the state. Areas with a history of Boone and Crockett or Pope and Young kills will likely have a higher hunter demand than areas without. The sign of $\frac{dF}{dX_1}$ is expected to be positive. Since hunter demand is likely to increase, it's appropriate to assume the level of harvest will also increase, $\frac{df}{dX_1}$ is positive. Wolves do not affect the antler size of game taken, making $\frac{dg}{dX_1}$ zero.

As the elk population increases $\frac{df}{dX_2}$, $\frac{dF}{dX_2}$, and $\frac{dg}{dX_2}$ should all increase. The higher the elk population, the more permits, leading to an increase in harvest. Similarly, the more game available the easier it is for wolves to find food, allowing them to nourish their young, and increase their population.

As snow falls in November, elk are pushed down from higher elevations. This makes them more accessible to hunters and easier to locate. Due to these observations the harvest $\frac{df}{dX_3}$ should increase with respect to November snowfall. Hunters on the other hand are predetermined. The application process and the drawing of permits have already taken place, fixing the number of hunters in the field. Due to this process $\frac{dF}{dX_3}$ is zero. As shown in the system of equations, wolf populations are a function of exogenous variables, November precipitation being one of them. Early snowfall may make killing animals harder on wolves through inhibiting the chase portion of their attack. When snow is fresh, wolves are at the same disadvantage as game. Only when a crust forms and wolves can move across the top of the snow while heavier game fall through do wolves have the advantage. A negative effect is assumed for $\frac{dg}{dX_3}$.

November heating degree days (HDD) will follow the same assumptions made for snowfall. As the temperature gets colder more snow is likely. It may be assumed elk will move to lower elevations increasing harvest making $\frac{df}{dX_4}$ positive. No effect can be assumed for hunters ($\frac{dF}{dX_4}$) or wolves ($\frac{dg}{dX_4}$).

The distance to Yellowstone National Park is likely to have negative effects on hunters, harvest, and wolves ($\frac{df}{dX_5}, \frac{dF}{dX_5}, \frac{dg}{dX_5}$). Areas around Yellowstone have been notorious for having a high number of hunters and harvest of elk. As large numbers of elk migrate outside park boundaries they make easy targets for hunters. Since many hunters prefer these areas, the harvest is high. Wolves should also decrease as the distance to Yellowstone increases since this is where they were reintroduced. The amount of game available within the park combined with the bans on hunting make this area a predator's paradise. Competition for food is reduced and the risk of death from human encounters is diminished.

Due to the fact that wolves migrate from Canada, as the distance to the border increases the wolf population is likely to decrease, $\frac{dg}{dX_6}$ is negative. On the other hand elk populations are low in the northwest region of the state, because of this as the distance increases both hunters and harvest should also increase, $\frac{df}{dX_6}, \frac{dF}{dX_6}$ are positive.

The last step in the comparative static analysis is to use Cramer's rule to determine how the endogenous variables are affected by a change in the exogenous variables listed above. By substituting the signs of each derivative into matrix Y, the determinant of Y_j can be calculated. The ratio $\frac{|Y_j|}{|Y|}$ then gives the results to this analysis (equation 11).

(11) $$\frac{dH}{dx_j} = \frac{|Y_j|}{|Y|} = \frac{?}{+}$$

Table 5.2 summarizes the results of this analysis and are as follows: (1) as trophy game increases, the number of hunters and harvest of elk can be expected to increase, with no effect on the population of wolves. (2) As the elk population increases the wolf population will also increase. However, no signs could be determined with respect to the effects on hunters or harvest. (3) November snowfall is expected to have no effect on hunters, a negative effect on wolves, and a positive effect on harvest. (4) HDD's in November are expected to increase harvest with no effect on hunters or wolves. (5) The distance to Yellowstone National Park is expected to have a positive effect on harvest, an undetermined effect on hunters, and a negative effect on wolves. (6) The distance to the Canadian border is expected to have a negative effect on wolves, and a positive effect on hunters and harvest.

Table 5.2 Comparative Statics						
	Trophy	Elk pop.	Nov. Snowfall	Nov. HDD's	Dist. to YNP	Dist. To CAN
Harvest	$\frac{dH}{dx_1}$>0	$\frac{dH}{dx_2}$=?	$\frac{dH}{dx_3}$>0	$\frac{dH}{dx_4}$>0	$\frac{dH}{dx_5}$>0	$\frac{dH}{dx_6}$>0
Hunters	$\frac{dK}{dx_1}$>0	$\frac{dK}{dx_2}$=?	$\frac{dK}{dx_3}$=0	$\frac{dK}{dx_4}$=0	$\frac{dK}{dx_5}$=?	$\frac{dK}{dx_6}$>0
Wolves	$\frac{dW}{dx_1}$=0	$\frac{dW}{dx_2}$>0	$\frac{dW}{dx_3}$<0	$\frac{dW}{dx_4}$=0	$\frac{dW}{dx_5}$<0	$\frac{dW}{dx_6}$<0

EMPIRICAL MODELS AND RESULTS

6.1 Empirical Models

The empirical models developed in this thesis quantify the effect of wolves on hunter applications, and the harvest of elk throughout Montana. In the development of these models assumptions were made and therefore must first be addressed.

Due to differences in prey composition throughout Montana the impact of wolves on elk can vary by region. Three distinctions were made between wolf populations and hunting districts. First, since southwest Montana is in close proximity to YNP it will be analyzed separately. The elk population dynamics in this area are thought to be different from dynamics seen throughout other portions of the state. Elk migrate in and out of YNP where hunting is banned, making populations higher and more condensed. In northwestern Montana wolves have been found to prey primarily on deer. Due to this finding this area will be classified separately. The west central portion of the state where wolves are migrating from Canada and Yellowstone will be the third portion analyzed. It is important to note these regions correspond to hunting districts established by MFWP. Southwest Montana corresponds to the 300 districts, west central to the 200 districts, and northwest to the 100 districts.

Due to lack of adequate data on elk populations, the models used in this paper will estimate the impact wolves are having on the elk harvest and hunter applications by region. A recursive system based on equation 7 will be set up to first estimate wolf populations based on weather variables, the wolf population from the previous year, and the game harvest the previous year. Next, hunter applications will be estimated using wolf population, trophy game, city distance, and harvest from the previous year. Finally, elk harvest will be estimated using wolf population, hunter applications, weather variables, last year's harvest, and distances to YNP or the Canadian border.

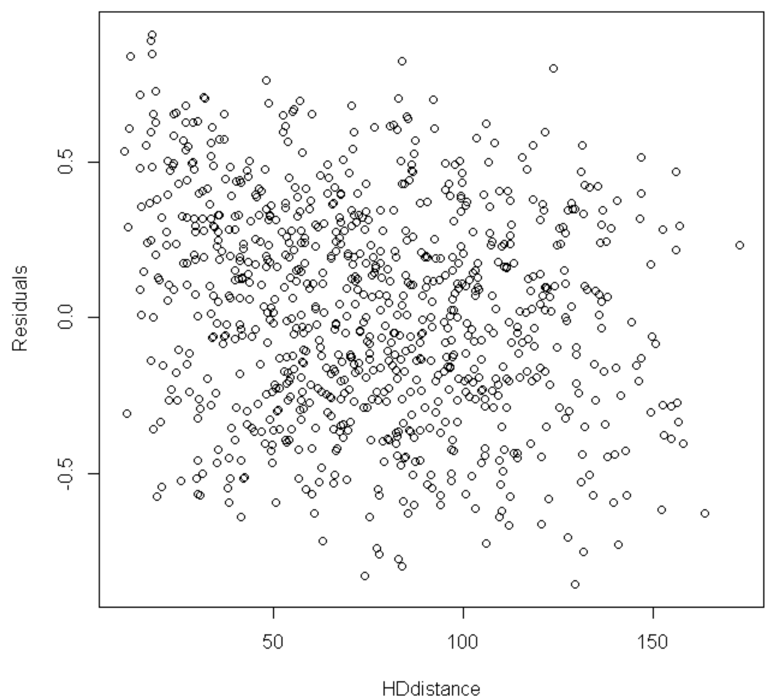


Figure 6.1 Spatial Residuals in SW MT

Prior to analysis the data used in this thesis was normalized. Due to this process estimates contained in regression results must be multiplied by the standard deviation of each variable to determine the actual effect. Refer to tables 4.1 through 4.3 for summary statistics. Spatial correlation between elk harvest and hunting districts was addressed however, none was found. As depicted in figure 6.1, no trend is present between the residuals of the model and distance to hunting districts.

Next, a two stage process was set up. In the first stage an OLS regression was run on each equation separately. The endogenous variables; wolves, hunter applications, and hunter harvest were estimated using all exogenous variables. The endogenous variable residuals from these estimations were then plugged into the actual equations used in this analysis (wolf population residuals & hunter application residuals). Since the coefficient on wolf population residuals was not significantly different from zero we failed to reject the null hypothesis that there was no simultaneity bias present within the hunter applications model. On the other hand, we rejected the null hypothesis that no simultaneity bias was present within the harvest model since the estimated coefficient on hunter application residuals was significant. This test is equivalent to a Hausman test. This identified a possible feedback relationship between one or more of the independent variables and the dependent variable causing OLS coefficients and standard errors to be biased (Greene, 2008, p. 339).

The second stage of this process replaced the hunter application variable with fitted values obtained from the first stage process. The standard error of the first stage was compared to the standard error of the second stage, and consistent with recursive model corrections the error increased. To correct for the bias in the harvest coefficients the following corrections were used. Adjusted standard errors were computed by taking the standard error of each variable multiplied by the ratio of the second stage standard error and the first stage standard error. Adjusted t-statistics were computed by dividing each variable’s coefficient by the adjusted standard error. Two-tailed tests were run to determine the adjusted p-value of each variable, unless comparative static analysis signed a variable, in which a one-tailed test was used. The remainder of this chapter contains three sections: Wolf Population Models, Hunter Demand Models, and Hunter Harvest Models. These sections will contain a general discussion of model results by region.

6.2 Wolf Population Models

Table 6.1 depicts the estimation results of wolf populations by region in Montana. In every region lagged wolf population was significant at the 1% level. The positive coefficient indicates that the current year's population is positively impacted by the population from the previous year. The previous year's elk harvest is only significant in the southwest (10% level), with a positive effect on wolves.

Changes in heating degree days (HDD's) depict how severe each month was compared to previous years. The negative coefficient on February HDD's indicates that when temperatures fall, wolf packs throughout the state will be negatively impacted. However, when we look at April HDD's only wolves in southwest (positively) and west central (negatively) will be impacted. Changes in HDD's from October the previous year will negatively impact wolves in both the southwest and northwest portion while the previous year's December HDD's will positively impact wolves in every region.

Precipitation has different effects across the state, increases in yearly precipitation impact southwestern wolves negatively while increases in last year's precipitation impact them positively. No effect was found for the west central or northwest regions. Changes in precipitation from the previous year's spring (April and May) have different regional effects. In the southwest lagged spring precipitation decreases wolf populations. In the west central portion lagged May precipitation has a positive effect. In the northwest portion lagged spring precipitation also has a positive effect on wolves. Lagged November snowfall has negative effects in both southwest and northwest Montana, while lagged December snowfall has a positive effect only in the west central region.

The results of this model show that regardless of region, wolves are likely to continue to increase. Since weather has both negative and positive effects the only way to deal with overpopulation is through predator control programs. Although Montana has implemented wolf hunts in 2009 and 2011, their impact cannot yet be determined due to limited data.

6.3 Hunter Demand Models

Table 6.2 depicts estimation results for hunter demand by region. The dependent variable used to estimate changes in hunter demand is first choice hunter applications. Since wolves migrate to Montana out of YNP and Canada, each region will be analyzed separately. Interactions between wolf population and the distance to YNP/Canada were used for the southwest and northwest regions. The most significant finding of this model is that wolf population has a negative effect on hunter applications, significant at the 1% level in both the southwest and west central regions. In the southwest, as wolf population increases, hunter applications decrease by 19.9% of the standard deviation. In west central the decrease is much less, 2.9% of the standard deviation. This corresponds to 286 fewer applications in the southwest, but only 6 fewer in west central Montana. In Northwest where elk hunting is limited, wolves have no effect on hunter applications.

Table 6.1 Wolf Population Results by Region

	Southwest	W. Central	Northwest
Intercept	0.017	0.160***	0.381***
	(0.034)	(0.040)	(0.121)
Wolf Pop$_{(t-1)}$	0.715***	0.638***	0.716***
	(0.031)	(0.042)	(0.073)
Yearly Precipitation$_{(t-1)}$	0.288***	0.075	0.129
	(0.067)	(0.077)	(0.084)
Yearly Precipitation	-0.146**	-0.071	-0.128
	(0.071)	(0.076)	(0.084)
Change in January Precipitation	0.056	-0.133***	0.120***
	(0.045)	(0.042)	(0.035)
Change in February HDD's	-0.142***	-0.305***	-0.390***
	(0.032)	(0.053)	(0.114)
Change in February Precipitation	0.045	-0.025	0.112**
	(0.038)	(0.041)	(0.047)
Change in March Precipitation	0.010	0.166***	-0.072
	(0.044)	(0.043)	(0.051)
Change in April Precipitation$_{(t-1)}$	-0.126***	-0.029	0.154**
	(0.035)	(0.044)	(0.064)
Change in April HDD's	0.074***	-0.128**	0.330
	(0.025)	(0.052)	(0.199)
Change in April HDD's$_{(t-1)}$	-0.070**	-0.274***	-0.212
	(0.032)	(0.072)	(0.211)
Change in May Precipitation$_{(t-1)}$	-0.210***	0.124**	0.241***
	(0.041)	(0.054)	(0.076)
Change in October HDD's$_{(t-1)}$	-0.099***	0.081	-0.220**
	(0.033)	(0.053)	(0.100)
Change in November Precipitation$_{(t-1)}$	-0.185***	0.055	-0.124***
	(0.064)	(0.045)	(0.042)
Change in December Precipitation$_{(t-1)}$	0.057	0.134***	-0.012
	(0.043)	(0.039)	(0.040)
Change in December HDD's$_{(t-1)}$	0.112***	0.409***	0.345***
	(0.042)	(0.068)	(0.116)
Harvest$_{(t-1)}$	0.042*	-0.020	0.028
	(0.023)	(0.044)	(0.088)
Adjusted R-squared	0.802	0.764	0.809
Residual SE	0.432	0.509	0.518
DF	281	238	103

Notes: Coefficients denoted with three, two, or one stars denote significance at the 1%, 5%, and 10% respectively. Standard errors are shown in parentheses under the coefficients.

Other variables in southwest Montana significant at the 1% level are lagged total harvest, city distance, and the number of successful applicants. Both lagged harvest and successful applicants have a positive effect while city distance has a negative effect. As the distance from hunting districts to major Montana cities increase the number of applicants will decrease.

In west central Montana variables significant at the 1% level include lagged harvest, successful applicants, and surplus applicants. City distance is significant at the 5% level. City distance and surplus applications both have a negative impact on hunter applications, while applicant success and lagged harvest have a positive impact. The intercept term and lagged harvest are the only variables significant in northwest Montana. The only conclusion from this model is that wolves and drawing statistics do not explain hunter applications within this region.

Table 6.3 depicts hunter demand models with interaction terms between wolf populations and the distance to YNP/Canada. The results for the southwest region are similar to above. Lagged total harvest and lagged drawing success have positive effects on the current year's harvest while city distance has a negative effect. The intercept term for 25-50 miles from the park is significant at the 5% level, while the intercept term for 50-75 miles away from the park are significant at the 10% level. Each coefficient has a negative effect on hunter applications, found by adding the coefficient from the less than 25 mile distance intercept coefficient. This implies that hunter applications decrease as you get further from the park. The effect of wolves is found by interactions between their population and the distance to YNP. Wolf populations within 25 miles of YNP are significant at the 5% level and wolf populations within 25-50 are significant at the 10% level. The difference is that wolves within 25 miles of YNP decrease hunter applications by 35.6% of the standard deviation while wolves within 25-50 miles increase applications by 11.3%. This effect may be due to game being pushed out of areas close to the park and moving to areas approximately 50 miles away. Hunters are adjusting to this migration by shifting applications to these districts.

In the northwest region, table 6.3, variables significant at the 1% level include the intercept term (districts within 25 miles of Canada), the intercept term for districts ranging between 50-75 miles, and lagged harvest. City distance, mean score of animals taken, and the intercept term for districts between 75-100 miles are significant at the 10% level. In this region as the distance to major Montana cities increase, hunter applications also increase. The mean trophy score of animals taken has a negative effect on hunters and is the opposite effect than predicted in our comparative static analysis.

Table 6.2 Hunter Application Results by Region

	Southwest	W. Central	Northwest
Intercept	-0.447***	-0.340***	-0.163***
	(0.100)	(0.034)	(0.031)
$Harvest_{(t-1)}$	0.466***	0.054***	0.309***
	(0.080)	(0.014)	(0.042)
Wolf pop	-0.199***	-0.029***	-0.001
	(0.071)	(0.010)	(0.010)
City Distance	-0.429***	-0.067**	-0.027
	(0.129)	(0.026)	(0.033)
Mean Trophy Score	0.099	0.006	-0.013
	(0.083)	(0.015)	(0.010)
Drawing Success	0.490***	0.216***	0.030
	(0.093)	(0.026)	(0.070)
Drawing Surplus	-0.077	-1.169***	NA
	(0.101)	(0.293)	NA
Adjusted R-squared	0.427	0.477	0.697
Residual SE	1.117	0.147	0.125
DF	291	248	114

Notes: Coefficients denoted with three, two, or one stars denote significance at the 1%, 5%, and 10% respectively. Standard errors are shown in parentheses under the coefficients. Shaded boxes denote where one-tailed tests were used.

Table 6.3 Hunter Applications in Southwest and Northwest Regions with Interactions

Southwest			Northwest		
	Estimate	SE		Estimate	SE
HD (<25M) Intercept	-0.130	0.247	HD (<25M) Intercept	-0.182***	0.045
HD (25-50M)	-0.852**	0.341	HD (25-50M)	0.048	0.044
HD (50-75M)	-0.640*	0.327	HD (50-75M)	0.128***	0.049
HD (75-100M)	-0.350	0.412	HD (75-100M)	-0.066*	0.047
HD (100-125M)	-0.467	0.298	$Harvest_{(t-1)}$	0.216***	0.047
HD (125-150M)	-0.401	0.369	City Distance	0.076*	0.044
$Harvest_{(t-1)}$	0.441***	0.082	Mean Trophy Score	-0.015*	0.010
City Distance	-0.471***	0.137	Drawing $Success_{(t-1)}$	0.091	0.072
Mean Trophy Score	0.084	0.082	Drawing Surplus $_{(t-1)}$	NA	NA
Drawing $Success_{(t-1)}$	0.531***	0.096	Wolf pop (<25M)	0.005	0.024
Drawing $Surplus_{(t-1)}$	-0.104	0.100	Wolf pop (25-50M)	0.023	0.028
Wolf pop (<25M)	-0.356**	0.165	Wolf pop (50-75M)	-0.035	0.030
Wolf pop (25-50M)	0.469*	0.255	Wolf pop (75-100M)	-0.014	0.035
Wolf pop (50-75M)	0.012	0.408			
Wolf pop (75-100M)	-0.563	0.535			
Wolf pop (100-125M)	0.443	0.291			
Wolf pop (125-150M)	0.343	0.496			
Adjusted R-squared	0.460		Adjusted R-squared	0.727	
Residual SE	1.085		Residual SE	0.119	
DF	281		DF	108	

Notes: Coefficients denoted with three, two, or one stars denote significance at the 1%, 5%, and 10% respectively. In each model HD denotes distance intervals of 25 miles from YNP/Canada. Shaded boxes denote where one-tailed tests were used.

6.4 Elk Harvest Models

The current year's elk harvest is the dependent variable used in this analysis. Following the Hunter Demand Model, interaction terms between wolf population and the distance to YNP/Canada were used for the southwest and northwest regions. Interaction terms were setup between wolves and individual hunting units for the west central portion of the state since wolves migrate to this area through both corridors.

Table 6.4 summarizes harvest results for southwest Montana. In this region, three variables were significant at the 1% level; lagged harvest, change in November HDD's, and the hunter application fitted values obtained from the first stage process. The positive coefficient on lagged harvest indicates harvest should increase in the current year. When an area is known for producing large amounts of elk, more hunters will choose to hunt in this area, increasing harvest. Also large game herds are associated with a larger gene pool, and an increase in young, sustaining or increasing the population each year. The positive coefficient on November HDD's is in line with the comparative static results discussed in Chapter 5. Colder temperatures are associated with increases in snowfall, pushing elk down from higher elevations and increasing harvest by hunters. Finally, hunter applications have a positive effect on harvest. Increases in hunter applications indicate higher demand. Since permit supply is fixed, if and when a hunter draws a permit they are more likely to fill the tag than in areas associated with low demand. This may happen because determined hunters are hunting in areas associated with positive game attributes.

Northwest Montana harvest results are shown in the right hand side of table 6.4. In this region the intercept for districts within 25 miles of Canada and yearly precipitation are significant at the 10% level. Hunter applications and the previous year's change in November HDD's are significant at the 5% level. All significant variables have positive coefficients on harvest throughout this region. The positive coefficient on yearly precipitation indicates elk in this region may frequent higher elevations, remotely located from hunters. As snowfall increases this will make elk more accessible and increase harvest. Also as applications increase the harvest will increase since competition is increased creating more determined hunters.

Table 6.5 summarizes harvest results for the west central portion of Montana. The results here differ from above since wolf population was interacted with individual hunting units. If a HD interaction term is significant this indicates the intercept for this district is different from the overall intercept. Intercepts for hunting districts 204, 210, 212, 215, 240, 250, 270, 292, and 293 are found by taking each unit's coefficient plus the overall intercept term. Since the coefficients on all of these units are positive they have a higher starting harvest than other units within this region. Lagged harvest, quota, and change in November HDD's are significant at the 1% level. The positive coefficients on these variables indicate that as they increase harvest will also increase, holding all else constant. The sign on change in November HDD's is consistent with prior analysis. The fitted values of hunter applications attained from the first stage process are also significant at the 1% level however this variable has a negative effect on harvest. In this region as applications increase harvest will decrease. The wolf population for district 215 is significant at the 5% level and has a positive effect on harvest. Overall, wolves did not affect harvest in this region.

Table 6.4 Harvest Results for Southwest and Northwest Montana with Interactions

Southwest			Northwest		
	Estimate	SE		Estimate	SE
HD (<25M) Intercept	0.208	0.321	HD (<25M) Intercept	1.018*	0.633
HD (25-50M)	0.172	0.364	HD(25-50M)	-0.029	0.114
HD (50-75M)	0.143	0.390	HD (50-75M)	0.049	0.143
HD (75-100M)	-0.228	0.504	HD (75-100M)	-0.164	0.156
HD (100-125M)	0.014	0.378	Yearly Prcp.	0.065*	0.038
HD (125-150M)	-0.14	0.432	$Harvest_{(t-1)}$	0.26	0.187
Yearly Prcp.	0.023	0.124	Quota	8.024	5.200
$Harvest_{(t-1)}$	0.408***	0.123	Yearly HDD's	-0.074	0.065
Quota	-0.059	0.072	Change in Nov. HDD's	0.09**	0.051
Yearly HDD's	-0.026	0.091	Change in Nov. Prcp.	0.012	0.019
Change in Nov. HDD's	0.344***	0.059	Hunter Apps. (fitted)	1.248**	0.548
Change in Nov. Prcp.	0.009	0.107	Wolf pop (<25M)	0.029	0.069
Hunter Apps. (fitted)	0.475***	0.139	Wolf pop (25-50M)	-0.018	0.080
Wolf pop (<25M)	0.186	0.174	Wolf pop (50-75M)	-0.021	0.083
Wolf pop (25-50M)	-0.101	0.268	Wolf pop (75-100M)	-0.03	0.097
Wolf pop (50-75M)	-0.079	0.435			
Wolf pop (75-100M)	-0.645	0.557			
Wolf pop (100-125M)	-0.11	0.309			
Wolf pop (125-150M)	-0.005	0.520			
Adjusted R-squared	0.771		Adjusted R-squared	0.846	
Residual SE	0.57		Residual SE	0.245	
DF	279		DF	105	

Notes: Coefficients denoted with three, two, or one stars denote significance at the 1%, 5%, and 10% respectively. In each model HD denotes distance intervals of 25 miles from YNP/Canada. Shaded boxes denote where one-tailed tests were used.

Table 6.5 Harvest Results for West Central Montana with Hunting District Interactions

	Estimate	SE		Estimate	SE
Intercept	1.299***	0.478	(HD)293	0.928***	0.329
Yearly Prcp.	0.119	0.081	(HD)298	0.517	0.548
$\text{Harvest}_{(t-1)}$	0.250***	0.076	Wolf pop	-0.033	0.125
Quota	17.353***	3.714	Wolf pop (HD)201	0.022	0.156
Yearly HDD's	0.167*	0.095	Wolf pop (HD)202	-0.003	0.160
Change in Nov. HDD's	0.196***	0.039	Wolf pop (HD)203	0.006	0.212
Change in Nov. Prcp.	0.017	0.034	Wolf pop (HD)204	-0.125	0.177
Hunter Apps. (fitted)	-1.570***	0.562	Wolf pop (HD)210	-0.097	0.177
(HD)201	0.235	0.301	Wolf pop (HD)211	-0.099	0.186
(HD)202	0.272	0.254	Wolf pop (HD)212	0.310	0.279
(HD)203	0.329	0.269	Wolf pop (HD)213	0.268	0.322
(HD)204	0.932***	0.327	Wolf pop (HD)214	-0.139	0.215
(HD)210	0.893**	0.364	Wolf pop (HD)215	0.825**	0.411
(HD)211	0.240	0.321	Wolf pop (HD)216	-0.038	0.180
(HD)212	1.020**	0.412	Wolf pop (HD)240	0.101	0.185
(HD)213	0.213	0.354	Wolf pop (HD)250	-0.062	0.219
(HD)214	0.119	0.339	Wolf pop (HD)260	0.040	0.173
(HD)215	1.501***	0.383	Wolf pop (HD)261	0.008	0.181
(HD)216	-0.034	0.333	Wolf pop (HD)270	0.005	0.169
(HD)240	0.735**	0.309	Wolf pop (HD)280	-0.506	0.732
(HD)250	0.776**	0.316	Wolf pop (HD)281	0.019	0.186
(HD)260	-0.060	0.410	Wolf pop (HD)282	-0.100	0.242
(HD)261	0.316	0.353	Wolf pop (HD)283	0.026	0.183
(HD)270	2.488***	0.382	Wolf pop (HD)285	0.045	0.188
(HD)280	-0.316	0.519	Wolf pop (HD)291	-0.253	0.285
(HD)281	0.515	0.320	Wolf pop (HD)292	-0.104	0.185
(HD)282	-0.072	0.312	Wolf pop (HD)293	-0.076	0.271
(HD)283	0.338	0.308	Wolf pop (HD)298	-0.106	0.380
(HD)285	0.407	0.293	Adjusted R-squared	0.774	
(HD)291	0.450	0.342	Residual SE	0.399	
(HD)292	1.344***	0.349	DF	196	

Notes: Coefficients denoted with three, two, or one stars denote significance at the 1%, 5%, and 10% respectively. Hunting District changes in intercept denoted by (HD). Shaded boxes denote where one-tailed tests were used.

CONCLUSION

Montana's wolf population has exploded in the last decade through dispersal of wolves from Yellowstone National Park and Canada. Controversy over the impact of these predators on Montana's hunting and ranching industries have spurred MFWP to implement a wolf hunting season to manage this population. As stated by Batastini and Buschena (2007), "Constituency groups in general opposition of wolf recovery, ranchers and outfitters, bear the burden of its costs, while those in general support of wolf recovery, mainly environmentalists, pay very little."

Since wolves primarily prey on big game, Montana's hunting industry will likely be impacted in various ways. While studies have looked at wolf impacts on elk populations and distributions, few have analyzed the impact on the hunting industry. Batastini and Buschena (2007) is the only other study to date to analyze the impact of wolves on big-game hunting in Montana. Due to data limitations they were restricted to analyzing the effect of wolves between 1999 and 2002. As a result of this limitation the goal of this thesis was to develop a method to analyze the impact of wolves on elk hunting in Montana, extending the time period. By developing an empirical method to analyze wolf impacts, and presenting the results, we can better understand the effect wolves are having. The estimates in this thesis will provide hunters and MFWP information on how elk hunting has been impacted in different regions of the state.

While it would have been ideal to estimate wolf impacts on elk populations, accurate population counts were not available. Therefore, the models developed in this thesis assess how a proxy for hunter demand and harvest has changed. Data from MFWP harvest reports, drawing statistics, hunting regulations, wolf pack location, USFWS annual reports, and other sources were used to construct the models. The time period considered was from 1999 to 2010. A recursive model was set up to explain the effect wolves have on hunter applications and harvest. Due to differences in regional characteristics the southwest, west central, and northwest portions of the state were analyzed separately. The model results estimated no significant impact of wolves upon hunter harvest in any of the three regions analyzed. However, in both southwest and west central portions of the state wolves were found to decrease hunter applications. Overall, wolves decrease hunter applications by 19.9% of the standard deviation in the southwest and 2.9% of the standard deviation in the west central region. This corresponds to 286 fewer applications in the southwest, but only 6 fewer in west central Montana. When considerations were made for the distance to YNP, the southwestern region saw applications within 25 miles of the park decrease by 35.6%. Districts between 25 to 50 miles saw an increase of 11.3%. No effect was found in the northwestern region for the interaction term pertaining to wolves and the distance to Canada.

The implications of this study are as follows; using the current data available wolves are not having a significant effect on elk harvest in Montana. On the other hand, they are shifting demand in the southwest region from areas in close proximity to the border of YNP to areas farther away. This shift in demand may negatively impact MFWP since one of their major budget sources is through the sale of hunting licenses. Currently, the only other effect found was decreases in hunter applications in the west central portion. Although this result was highly significant the magnitude of this reduction was not. Overall, this empirical estimation found wolves are not having the effect on elk hunting in Montana as many people would think. However, it must be noted that hunter and harvest information, and wolf populations between the years prior to and between 1996-1998, when wolves were first reintroduced to YNP, has not been released by MFWP. This data would be useful in estimating the before and after effect of wolves in southwestern Montana. Accurate elk population data was limited, prohibiting the direct estimation of wolf impacts on elk populations.

The models developed in this thesis could also be used to estimate the impact of wolves on hunter applications and harvest of other game species. Information on how wolves impact the hunting of deer, moose, and elk may be of particular interest to MFWP and hunters. This study could also be extended to include other states where wolves have been reintroduced, such as Wyoming and Idaho. In addition, the time period used in this analysis is relatively short, with key pieces of information missing. The long run impacts of wolves may differ from those found here. Continual research and data improvement is recommended on this topic.

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