THE IMPACT OF WOLVES ON THE "MARKET" FOR ELK HUNTING IN MONTANA: HUNTER ADJUSTMENT AND GAME AGENCY RESPONSE

by

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ABSTRACT

The gray wolf has become a symbol of controversy in the American West. Hunters, however, are one group that has diverse attitudes toward wolf recovery stemming from the conflicting impacts the presence of wolves creates. Impacts on hunters and big-game populations also affect state game agencies. As of 2005, wolves are still managed by the federal government, so the impact of wolves is exogenous to state game agencies. However, state game agencies can exert control over how wolves affect hunters by adjusting management of big-game hunting. The purpose of this thesis is to develop a method to analyze the impacts wolves have on the big-game hunting "market" in the NRMRA, and to use this method to estimate the short-run impacts of wolves on elk hunting in Montana. A hunter choice model and a game agency model were used to form the basis of the empirical models. The dependent variables developed assess the impacts of wolves on the quality, quantity, and demand for limited elk hunting permits, and the quality of general license elk hunting in Montana. The wolf variables included in the models capture the initial elk distributional effects of wolves, the intensity at which wolves inhabit a hunting district, the level of wolves, and the longevity of wolves within a hunting district. The time period considered was limited by hunting and harvest data availability to 1999 to 2002. The results from the empirical estimations suggest that the state game agency and elk hunters are effectively adjusting to wolves in areas of Montana where wolves prey primarily on deer. In other portions of Montana where naturally occurring wolves prey primarily on elk, the results suggest that the state game agency and hunters are not adjusting to wolf predation as to maintain hunter harvest rates in these areas. Finally, in portions of Montana where reintroduced, high-profile wolves prey primarily on elk, the model results suggest that hunters and the state game agency is adjusting to wolf predation. However, despite the adjustment of the game agency hunter harvest is being affected in these districts.

CHAPTER 1

INTRODUCTION

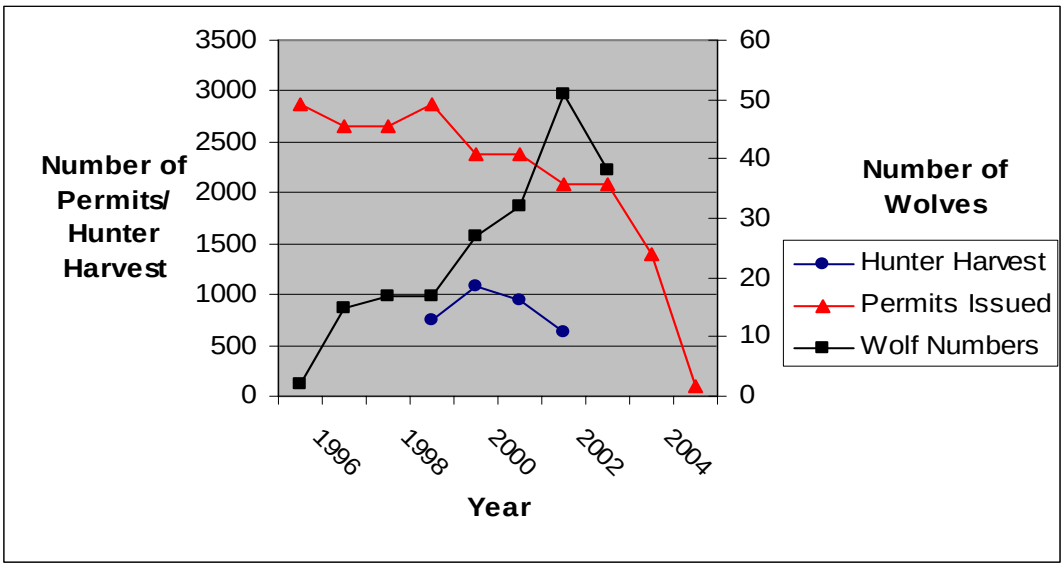
> "Some hunters, outfitters and politicians have blamed wolves for declining elk numbers. Park scientists maintain there are a variety of factors, like drought and other predators, at play in the 2.2 million-acre park. 'I'm real skeptical about all their reports,' said Bill Hoppe, a Jardine outfitter. 'We've had grizzly bears forever, and bad winters, and the elk have always done OK.' The elk herd began declining in 1996 after wolves were reintroduced, Hoppe said, 'and it's gotten smaller ever since.'" (McMillion 2003, "Elk...It's what's for Dinner")

The designation of the gray wolf as an endangered species by the federal government has brought the wolf to the forefront of controversy in the American west. The wolf has become more than just a species in need of recovery, it has become a symbol of controversy in the west between environmentalists and animal rights organizations on one side, and ranchers and outfitters on the other (Jones 2004; Magagna 2004; Thomas 2004). The main cause of the existing turmoil is that those in general opposition of wolf recovery bear the burden of the costs, while those in support of the recovery pay very little. The ongoing controversy over the wolf is evidenced by several local Montana newspaper articles with titles such as; "Killer wolf packs marked for death," "Migrating wolves complicate wildlife management," "Late hunt shrinking," "Elk calf numbers too low," and "Elk...it's what's for dinner" (Bozeman Daily Chronicle, various dates).

Hunters, however, are one group that has diverse attitudes toward wolf recovery (Glenn 2004). These diverse attitudes towards wolves among hunters in the Northern Rocky Mountain Recovery Area (NRMRA) stem from the conflicting impacts the

presence of wolves creates. On one hand, most hunters obtain value from the enjoyment of the hunt itself, aside from harvesting an animal. Hunters place a value on being out in the wilderness, away from civilization and in being among the West's abundance of wild animals. Many hunters purposefully choose hunting areas inhabited with grizzly bears and mountain lions, despite the additional costs associated with choosing to do so. Hunters choose to hunt in these areas because, all else equal, the additional value they receive from the presence of these large predators is greater than the costs associated with their presence. The additional value a hunter might receive includes chance sightings and encounters, as well as the existence value placed upon simply knowing these creatures inhabit the area. On the other hand, the costs associated with hunting an area inhabited by these predators include the predation effects on game herds, the likelihood of being attacked, and possibly killed, as well as the additional safety expenditures and precautions that many take when hunting in one of these areas. The reintroduction of the wolf has amplified both the costs and benefits of hunting in one of these large predator inhabited areas. These costs and benefits of hunting in a wolf inhabited area are dependent upon the game agency responsible for management of state game populations. How the state game agency responds to predation effects caused by wolves will greatly affect the ways big-game hunters are impacted. Impacts of wolves on big-game populations and hunters ultimately affect state game agency revenues as well. Therefore, the agency's response to wolves is dependent upon the impacts of wolf predation on big-game herds, hunter response to wolves, and the incentive structure of the state game agency.

Figure 1.1. Districts 313 and 314 wolf numbers, cow permit numbers, and hunter harvest.



Notes: Wolf numbers contained in figure 1.1 were obtained from Rocky Mountain Wolf Recovery Annual Reports and the Yellowstone Wolf Project, various years. The number of permits issued and the hunter harvest contained in figure 1.1 are from Elk Hunting and Harvest Annual Reports and Big-Game Hunting Regulations, respectively, published by Montana Fish, Wildlife, and Parks.

Since wolves were reintroduced in the Yellowstone region in the mid-1990s, both sides of the wolf argument have put forth opposing estimates of the impacts that a restored wolf population in the NRMRA would have on big-game populations in the region, as well as the impacts that will be incurred by big-game hunters in the region. While many wolf predation studies have been, and are currently being conducted, no studies on the impacts of wolf predation on big-game hunting in the NRMRA have taken place. Therefore, hunters weighing the costs and benefits of hunting in wolf-inhabited areas, as well as decisions of which side of the wolf argument to take a stance on may be doing so based on incomplete and sometimes faulty information.

The reduction in late season cow permits in Montana hunting districts 313 and 314 has been used as an example of the impact that wolves are having on hunting in this

area. Since the reintroduction of wolves permit numbers have dropped from 2,870 permits in 1996 to 100 in 2005 (MFWP Big-Game Hunting Regulations, various years). As shown in figure 1.1, as the number of wolves has increased in this district, the number of permits and hunter harvest has decreased. However, due to effects from the drought and predation from grizzly bear on elk populations, the wolf's contribution to this reduction in permit numbers and hunter harvest is unknown (McMillion 2003, "Elk...It's what's for Dinner).

The purpose of this thesis is to develop a method to analyze the impacts wolves have on the big-game hunting "market" in the NRMRA, and to use this method to estimate the short-run impacts of wolves on elk hunting in Montana. Two potential elk hunting "market" responses to wolves will be considered in this thesis. The first market response to the wolf's existence in Montana is how Montana Fish, Wildlife, and Parks (MFWP) adjusts its management strategy in response to wolves. MFWP may adjust permit numbers or hunting regulations in response to wolf predation. A model will be developed to estimate the response of MFWP to wolves. The second market response to the wolf's impact is through hunter demand. Wolf existence and predation, as well as how MFWP reacts to wolf predation, may impact hunter opportunity and the marginal value of hunting in Montana. A model of hunter demand will be developed to estimate how hunters are adjusting to wolves in Montana.

By creating a proper way to analyze wolf impacts, and presenting the results of these impacts, hunters will be able to base their hunting decisions and stances on the wolf issue accurately. Also, providing accurate estimates of the impacts of wolves on big-

game hunting in Montana as well as how hunters are responding to wolves will allow game agency officials to accurately estimate impacts of wolves on future periods' hunting license revenue as wolves spread to new hunting districts within the state.

The analysis in this thesis will proceed as follows. First, a literature review in Chapter 2 provides information on the history and biological factors of the gray wolf in the NRMRA. Chapter 3 will provide a discussion of the methods to assess the economic values of hunting in Montana, as well as the structure and incentives of Montana, Fish, Wildlife and Parks. From this information a model of hunter demand will be developed and used to construct a game agency model. Chapter 4 provides a discussion of the data used for the model estimations. The models, statistical procedures, and results of the econometric estimations are reported in Chapter 5. The conclusions and estimated response of hunters and the game agency to wolves in Montana are reported in Chapter 6.

CHAPTER 2

THE HISTORY AND BIOLOGY OF THE GRAY WOLF IN THE NORTHERN ROCKY MOUNTAIN RECOVERY AREA

The history of the gray wolf in the Northern Rocky Mountain Recovery Area (NRMRA) is full of conflict. Before the colonization of the west, wolves were a native species in the NRMRA. However, the historical abundance of the gray wolf in the region is unknown. Charles Kay, a well-known wildlife ecologist, pieced together journals from early explorers in the region and documented all journal recordings of any larger animals. The information Kay compiled from these journals, which recorded twenty expeditions, totaling 765 days in the Yellowstone area from 1835 to 1876, revealed that not one wolf was seen or killed. In addition, wolf howling was reported three times (Kay 1997, 28). Park Service records also seem to support this claim, suggesting that only between two and four packs inhabited Yellowstone. However, a possible reason for the low wolf populations in the park at the time is that intense native Indian hunting kept prey populations low, therefore limiting food for carnivorous species, such as the wolf (Kay 1997, 29).

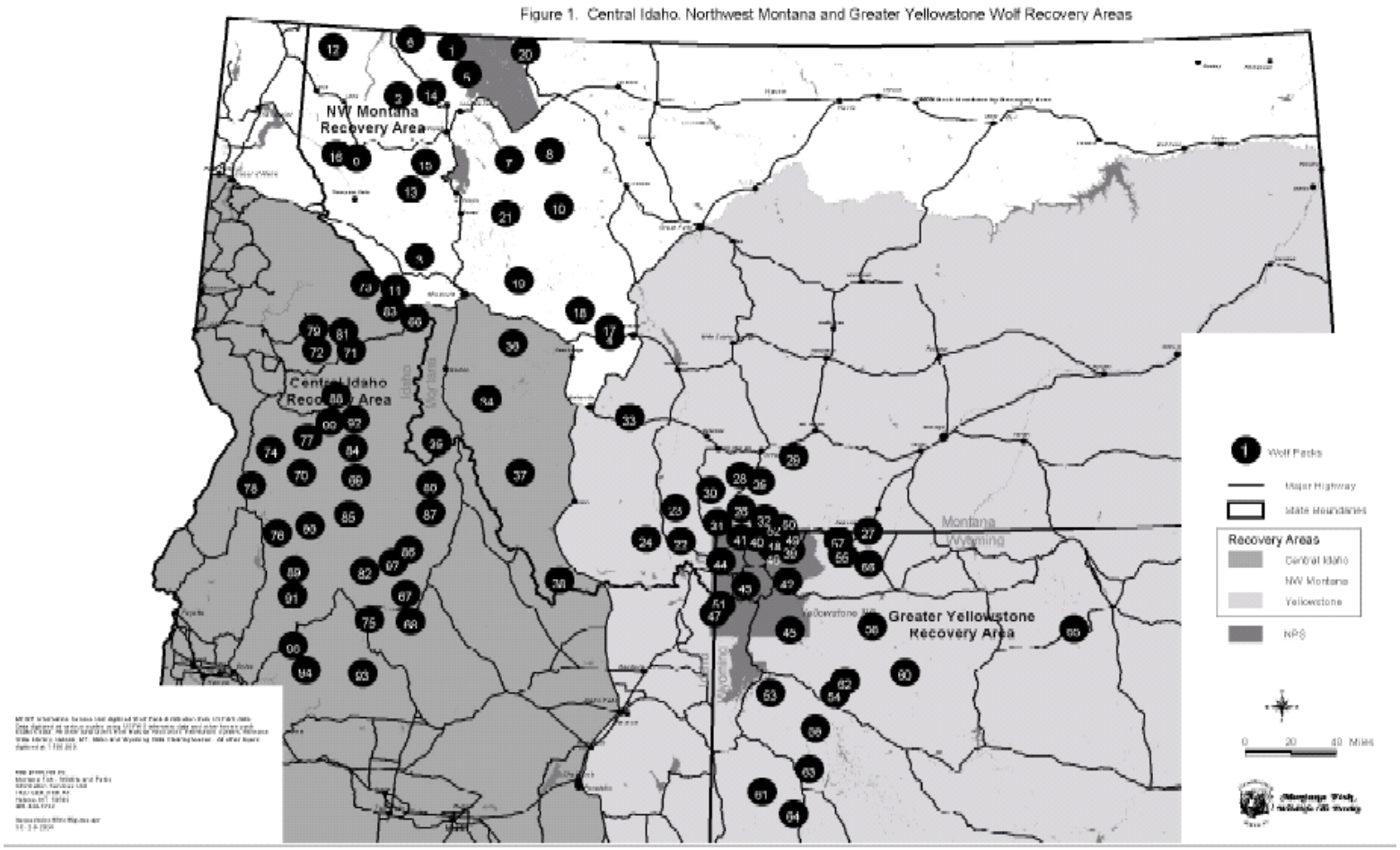
Throughout the late 1800s and early 1900s the Park Service practiced widespread predator control. Between 1914 and 1926, around 136 wolves were killed in Yellowstone Park alone (Defenders of Wildlife 2004). From the 1930s to the 1970s, wolves were rarely reported. Many naturally migrating wolves from Canada were killed throughout this period, thus leaving the NRMRA with no viable wolf population.

Wolves found protection with the passage of the Endangered Species Act (ESA) in 1973 (Defenders of Wildlife 2004). Wolves began migrating from Canada into the Glacier National Park area throughout the 1980s, with six packs inhabiting the area by 1995 (USFWS 2003, 2002 Rocky Mountain Wolf Recovery Report, 1). With the passage of the NRMRA wolf restoration plan, the federal government transplanted sixty-six wolves from southwestern Canada into Yellowstone National Park and Central Idaho throughout the mid-1990s. By the end of 2003, an estimated 761 wolves inhabited the NRMRA (USFWS 2004, 2003 Rocky Mountain Wolf Recovery Report).

The NRMRA is separated into three parts, 1) the Northwest Montana Recovery Area, 2) the Greater Yellowstone Recovery Area, and 3) the Central Idaho Recovery Area. The NRMRA map and wolf distribution as of the end of 2003 is shown in figure 2.1. The naturally occurring wolves in the Northwest Montana Recovery Area were classified as endangered, while the introduced wolves in the other two areas were classified as nonessential experimental populations. The nonessential experimental population designation allows for more flexible management of wolves than does the endangered status (USFWS 2003, 2002 Rocky Mountain Wolf Recovery Report, 1).

As of 2004, wolves were managed by federal agencies. However, the final rule to reclassify the gray wolf as a threatened species was made in 2003. If approval of Montana, Idaho, and Wyoming's wolf management plans occurs, the transfer of wolf management will be handed to each state game agency, subject to appeal in the judicial system.

Figure 2.1. NRMWRA map and wolf pack distribution.



Notes: Map obtained from the 2003 Rocky Mountain Wolf Recovery Report from the USFWS.

Wolf Biology

The biology of the gray wolf is the root of the controversy that surrounds it. Gray wolves in the NRMRA generally weigh about 90 to 110 pounds for males and 80 to 90 pounds for females (MFWP Final EIS 2003, 22). The gray wolf is a very social animal, most spending all of their lives in a pack. The pack consists of the alpha male and the alpha female, which are the breeding pair, the pups from the previous year's litter, new pups, and other breeding-aged adult wolves. Generally, the alpha male and alpha female are the only two breeding wolves in a pack. In the Greater Yellowstone Area (GYA), however, wolf packs occasionally have more than one litter per pack. In the NRMRA, the breeding season peaks in February. Wolves have around a 63-day gestation period and produce litters between one to nine pups (MFWP Final EIS 2003, 22). Wolf pup survival can be very high. In Yellowstone National Park in 2002 wolf pup survival was over 85 percent (Smith, Stahler, and Guernsey 2003, 3). Once the pups are born, a wolf pack remains close to the den site for around eight weeks. One problem associated with wolf reproduction is that wolves tend to make den sites in areas of low elevation, which in the NRMRA are usually inhabited by humans and livestock (MFWP Final EIS 2003, 23). Other than the pups' weaning period from April to September, a wolf pack will travel throughout its territory in search of prey. The diameter of a packs' territory ranges from 24 to 614 miles in Northwest Montana, and 33 to 934 miles in the GYA in 1999 (MFWP Final EIS 2003, 23).

Wolf Predation

Once matured, a member of a wolf pack will generally disperse to an uninhabited area and seek a mate, or join another pack. Wolves are known to disperse over wide ranges, thus allowing the population to spread fairly quickly. Wolves in Northwest Montana relocated on average sixty miles from their home territory. As populations continue to grow, wolf dispersal is becoming more and more common in areas like Montana (MFWP Final EIS 2003, 23).

The wolf is a very effective predator. While a single wolf is capable of killing a large ungulate, the pack is the wolves' most effective hunting strategy. On average, an adult wolf consumes about ten pounds of meat per day (International Wolf Center 2000). However, after several days without eating, a single wolf may consume up to twenty pounds of meat, or one-fifth of its body weight in a single day (International Wolf Center 2000). With a population of around 800 wolves in the NRMRA as of 2004 and an average of 10 pounds of meat consumed per day, about 3 million pounds of meat will be consumed by wolves in the NRMRA in one year. While the impacts on big-game populations may still be large if wolves consumed the whole animal, many studies show that wolves do not always consume the entire prey animal, thus using consumption estimates to infer ungulate predation by wolves could produce drastically understated numbers. Therefore, a more useful estimate is that of actual kill rates of wolves rather than consumption rates. For deer-killing wolves the highest reported kill rate is 6.8 kilograms per wolf each day (Mech and Peterson 2003, 143). However, kill rates for wolves preying on larger species are much higher. The highest reported kill rate by

wolves preying on larger species is 24.8 kilograms per wolf each day (Mech and Peterson 2003, 143).

Another reason using consumption estimates to estimate ungulate mortality due to wolf predation might underestimate its impact is what some have called “sport hunting,” or surplus killing by wolves. In these cases the wolves are killing more prey animals than they are able to consume, in some cases consuming no meat from the carcasses. There have been many documented cases of surplus killing by wolves (Mader 2004, 1). One conservation officer in Minnesota, while following two wolves, found that the wolves had killed twenty-one whitetail deer after a snowstorm, yet only fed partially on two of them. In another example, a pack of five wolves encountered a herd of 20 Dall rams. The pack killed every ram in the herd, but only fed upon six (Mader 2004, 1). Similar reports have come from the elk feeding grounds in Wyoming, where wolves prey on wintering herds.

The extent of the impact and frequency of surplus killing in the NRMRA is unknown, but some wolf studies reported it as a rarity. During a 30-year wolf-deer study, Mech only observed surplus killing by wolves on two occasions (Mech and Peterson 2003, 144). In most occasions of surplus killing by wolves the prey were more vulnerable than normal, usually due to environmental conditions. During one such incidence of surplus killing of caribou in Denali National Park, at least seventeen caribou were killed by six wolves. While the wolves did not consume much meat from the carcasses, scavengers had consumed about 30 percent to 95 percent of the carcasses within one

week, and after two months the wolves actually dug up some of the carcasses and fed upon them (Mech and Peterson 2003, 145).

Studies of Wolf Impacts on Big-Game Populations

Estimating the wolf's impacts on big-game herds in the NRMRA is a difficult task. Some ongoing studies in the NRMRA, as well as in other regions inhabited by the gray wolf, have produced some location specific data that proves useful in identifying the possible impacts wolf predation has had on big-game populations. Understanding how the predation effects of wolves impact the population dynamics of surrounding big-game herds is vital in understanding how these effects are translated to big-game hunters in the region.

Before wolves were reintroduced into the Yellowstone area, many preliminary estimates were produced for the potential impacts of wolves on ungulate populations in the NRMRA. The initial Environmental Impact Statement produced by the U.S. Fish and Wildlife Service (USFWS) was released in May of 1994. In the report, the USFWS stated that a population of 100 wolves in the Yellowstone area would reduce elk populations by 5 percent to 20 percent, mule deer by 10 percent, bison by 5 percent to10 percent, and leave other big-game species populations unaffected (USFWS Final EIS 1994, 2-42). Scientists from the University of Wyoming estimated reductions in elk populations from 15 percent to 25 percent, while a separate panel estimated reductions in moose populations by 10 percent to 15 percent and mule deer populations by 20 percent to 30 percent (Wolf Restoration to Yellowstone, www.nps.gov).

One source of big-game population data is the population surveys conducted by MFWP. These winter surveys count herded elk from the air in order to estimate the number of elk in particular areas. Additional flyover counts are conducted during the spring to determine an estimate of over-winter calf recruitment. The long-term average elk population for the northern Yellowstone herd from 1968 to 2002 is 13,846 elk. However, counts from recent years show this number declining quickly. In 2001, there was a count of 11,969 elk in the herd. In 2002, the count was 9,215 elk (MFWP Final EIS 2003, 48). One important note is that these elk counts vary drastically from year to year and are extremely sensitive to exogenous factors such as weather conditions. The weather during the 2002 count was very mild, thereby leaving elk with a wider distribution and more difficult to count. While weather conditions might be one contributing factor to the low 2002 count, biologists have concluded that elk populations have decreased. MFWP reports that numerous factors have contributed to the decline of the northern Yellowstone elk herd, but have not provided information on the relative importance of these effects. Some of these factors are predation, population effects of the drought, winterkill due to snow deep snow pack, as well as the Gardiner late season elk hunt (MFWP Final EIS 2003, 48).

In addition to the declining elk numbers shown by the winter counts, the spring counts of 2002 produced a record low calf to cow ratio of 14 calves to 100 cows. One reported reason for the lower recruitment rates is the higher predation. The lower recruitment rates experienced by the northern Yellowstone herd might have the potential to be traumatic for the herd because of its older age structure (MFWP Final EIS 2003,

49). An older age structure will lead to higher adult mortality in years to come. Combine this with record low recruitment rates and the long-term population trend of the herd could sharply decline.

While the population surveys do provide some data, they are of limited use for this thesis' emphasis. Year-to-year counts of the northern Yellowstone herd can fluctuate up to 30 percent to 40 percent, with general fluctuations of 10 percent to 20 percent. Other southwestern Montana herd counts also experience count fluctuations of 5 percent to 15 percent year to year (MFWP Final EIS 2003, 48). However, there is a lower count variation observed in other southwest Montana herds, which are for the most part managed by hunting, in comparison to the northern Yellowstone herd, which is managed by predation and hunting. The variation and extreme sensitivity of the counts to weather factors may limit the use these counts have to merely anecdotal evidence of the predation effects experienced by the northern Yellowstone herd (MFWP Final EIS 2003, 48). Models developed in further chapters will attempt to address the value of these counts.

Another source by which to view the effects of predation on big-game herds is the Yellowstone Wolf Project (Smith, Stahler, and Guernsey, 2003). The Yellowstone Wolf Project, which began in 1995, has studied many aspects of the lives of gray wolves in the GYA, including wolf-prey relationships and wolf kills. Throughout 2002 the project identified 291 elk, 21 bison, 4 deer, 4 coyotes, 4 wolves, 1 goose, 1 badger and 22 prey animals of unknown species killed by wolves. The elk, which made up 84 percent of the total animals killed, were composed of 34 percent calves, 31 percent cows, 22 percent

bulls, 5 percent of unknown sex, and 8 percent of both unknown age and sex (Smith, Stahler, and Guernsey, 2003).

In addition, two winter studies identified 122 elk that had been killed by wolves. The first of the winter studies identified 65 wolf-killed elk. The composition of the killed elk was 29 percent calves, 34 percent cows, 28 percent bulls, 6 percent of unknown sex, and 3 percent of both unknown age and sex (Smith, Stahler, and Guernsey 2003). The second of the studies found 57 wolf-killed elk. This study found the composition of wolf-killed elk as 39 percent calves, 26 percent cows, 32 percent bulls, and 3 percent adults of unidentified sex (Smith, Stahler, and Guernsey, 2003). From combined studies from 1995 to 2002, data showed that the composition of wolf-killed elk in the Northern Range of Yellowstone was comprised of 39 percent calves, 11 percent cows ages 1 to 9 years old, 29 percent cows of ages over 10 years, and 21 percent bulls. In addition, the study estimated that in the northern range of Yellowstone wolves on average killed 1.8 elk per wolf each month during the winter (Smith, Stahler, and Guernsey 2003).

A similar wolf predation study was conducted in Denali National Park in Alaska. During this study, which used data collected from tracking radio collared wolves in various packs from 1986 to 1991, a total of 294 moose, 225 caribou, and 63 sheep remains were examined. It was determined that of the animals examined, 245 moose, 221 caribou, and 60 sheep were killed by wolves. The study did stress that because moose carcasses are much easier to spot from the air than are sheep carcasses, a bias does exist that could misstate the actual proportion that sheep contribute to the wolf's diet (Mech,

Meier, Burch, and Adams 2000). Aside from this potential bias, this study does show a number of interesting points.

The results of the Denali study showed that, of the wolf-killed moose observed, there was no significant difference between the sex ratio of the moose population and the sex ratio of the wolf-killed moose. This finding suggests that in Denali the wolf is an equal opportunity predator when it comes to the moose. The study further revealed that the sex ratio of wolf-killed caribou was significantly different than the sex ratio of the population, with more male caribou being killed by wolves than the ratio of the caribou population (Mech, Meier, Burch and Adams 2000). This finding suggests that wolves actually prefer, or target male caribou. Another finding presented in this study is that when surplus killing of caribou took place the wolves did return multiple times to feed on the leftover carcasses (Mech, Meier, Burch and Adams 2000).

A study of wolves in the winter-feeding grounds of Wyoming provided different results than the two studies previously discussed. A study of wolf-killed elk in these areas showed that 53 percent were calves, 43 percent were cows, and 4 percent were bulls. The study also examined the carcasses of wolf kills and estimated a consumption rate of 83 percent. However, surplus killing of elk was documented on six separate occasions. Another finding of the study was that cow-calf ratios had fallen from a five-year average of 24:100, to 17:100 (USFWS 2003, 2002 Rocky Mountain Wolf Recovery Annual Report, 15).

The predation effects on big-game herds fluctuate with varying environmental conditions, particularly snowfall levels. Mech and Adams reported that in Denali

National Park during two severe winters wolf numbers increased dramatically. During this time, the percent of caribou calves that lived to four months was only 9 percent (Adams and Mech 2004, 3). While during the light snow winters almost 60 percent of the calves lived to four months. In addition, the caribou herd dropped from a population of 3,300 to 1,700 during this three-year period. An important note is that the decline in the prey population drove the wolf population to decline by 23 percent as well (Adams and Mech 2004, 3). The population trends of the Denali herds were also consistent with other herds in the region exposed to hunting. In these areas hunting seasons had to be closed due to the declines in the caribou populations (Adams and Mech 2004, 3). The results of this study show how the impacts of predation on big-game herds combined with extreme environmental factors can drastically reduce big-game populations.

Not all areas of the NRMRA exhibit the same big-game population structure as that of the GYA. Northwest Montana, for example, has a significantly different big-game population than does southwest Montana (MFWP Final EIS 2003, 22). In southwest Montana elk comprise a larger percentage of the big-game population than that of Northwest Montana, where deer comprise most of the big-game population. The composition of the wolf's diet in the Northwest Montana Recovery Area (NWMRA) is much different than that of the GYA wolves. In the NWMRA the wolf's diet consists of 83 percent white-tailed deer, 14 percent elk, and 3 percent moose (MFWP Final EIS 2003, 22). These prey composition differences mean that impacts of wolves in the NWMRA will be felt in a much different way than that of the populations in the GYA.

An additional factor that might prove to amplify the effect of wolf predation on big-game populations is the presence of other large predators in wolf-inhabited areas. The other large predators inhabiting NRMRA include black bears, grizzly bears, mountain lions, and coyotes. While both species of bears rely heavily on vegetation, bears typically prey on ungulate calves in the spring and male ungulates weakened from the fall rut (Griztrax.net 2004). Both black and grizzly bears coexist with wolves in the McGrath Area of Alaska. In the McGrath Area, both species of bear, as well as wolves, kill moose calves in the spring, while grizzly bears kill adult moose throughout spring and summer (Alaska Department of Fish and Game 2004, Potential Interactions between Bears, Wolves, and Moose in Alaska). In addition, bears scavenge ungulate carcasses when available. The additional carcasses available for bears to scavenge on due to year-round wolf predation provide bears with more food. Bears often displace feeding wolves from ungulate carcasses (Griztrax.net 2004). One effect in these multiple predator areas is that scavenging bears might reduce the amount of meat a kill might provide to a wolf pack, which might cause wolves inhabiting an area with higher bear populations to exhibit higher kill rates than those areas inhabited by wolves alone. The higher the bear population in a wolf pack's territory, the greater this effect is likely to be. Therefore, a territory inhabited by both bears and wolves is likely to exhibit greater predation effects than an area inhabited by wolves alone. In addition, the presence of coyotes, a well-dispersed scavenger in the NRMRA, and mountain lions in a wolf-inhabited area might also add to the effects wolves have on game herds in a given area.

While each of these studies present useful information on how the wolf is impacting local big-game herds in the short-run, no one knows what the restored wolf population in the NRMRA will do to the long-run population dynamics of big-game herds in the area. Populations of moose and caribou in Canada and Alaska that are free from heavy predation pressure have population densities of over ten times greater than those exposed to heavy predation (Kay 1997, 13). Kay (1997) uses the comparison of the moose populations in British Columbia to those in Sweden and Finland combined to show the long-run effects heavy predation can have on game populations. British Columbia contains roughly the same amount of moose habitat and is about the same size as the combination of Sweden and Finland. Moose populations in British Columbia are subject to predation from mountain lions, black bears, grizzly bears and wolves, while moose populations in Sweden and Finland are subject to almost no predation. Sweden and Finland's moose population during the 1980s was around 400,000, and increasing each year (Kay 1997, 13). During the same period, the moose population in British Columbia was around 240,000, and declining. In addition, hunter harvest in Sweden and Finland was 57 percent of the precalving population, while that of British Columbia was only 5 percent of the precalving population (Kay 1997, 13). While varying conditions do account for some of the difference in moose populations between the two areas, the main difference is the long-run impact that predation has had on British Columbia's moose populations (Kay 1997, 13).

The above studies and examples provide some insight in how wolf predation might be affecting the big-game populations in the NRMRA. However, more area

specific information is needed. Some ongoing studies that will provide such information are being conducted in the Madison Valley and in Gallatin Canyon in southwest Montana, as well as the Madison-Firehole area of Yellowstone National Park. The research addresses the different ways wolves are affecting elk populations within these specific areas (Creel and Winnie 2004). This study runs through 2005 and may provide interested parties with important information on all the impacts that wolves are having on elk herds in the NRMRA. Some preliminary results of these studies have also been released.

Gude and Garrott report that in the Lower Madison Valley study area elk comprised of 74 to 93 percent of wolf predation during the three winter seasons studied (Gude and Garrott 2003). They also found that calves made up 64 to 88 percent of the total elk killed by wolves. Kill rates of elk by wolves were found to be between 11.2 and 13.75 per wolf per 100 days (Gude and Garrott 2003). While these results do prove useful in showing the predation rates of wolves on this local population of elk during the winter months, it is limited in that the study period encompasses only the winter months and may not be an accurate representation of wolf predation throughout the remainder of the year.

The results from Montana's Gallatin Canyon study provide a depth of insight into how wolves are affecting elk populations, not only through direct predation, but through the spatial and distributional effects wolves have on the elk herds in the area (Creel and Winnie 2004). The study area includes four drainages in the Gallatin Canyon, northwest of Yellowstone, which encompasses much of the winter grounds to Yellowstone Park's

Gallatin elk herd. Since wolf colonization, early winter elk calf recruitment rates have been below 20 calves to 100 cows for five of the last six winters. These recruitment rates were only below that level in one of thirteen winters before wolves colonized the area (Creel and Winnie 2004). Population counts since wolf colonization of the area have been less than 1,500 elk for six out of the last seven winters, while only sixteen of forty-one winters prior to wolf colonization had elk populations below 1,500 (Creel and Winnie 2004). Creel and Winnie found that in the study area bull elk were 6.3 times more likely to be killed by wolves than were cow elk. These studies also showed that when wolves were present elk were less likely to stray away from timbered areas and that when wolves were present, elk herd sizes halved (Creel and Winnie 2004). The reduction in herd size due to the presence of wolves was caused by cow dispersal into smaller groups and bulls leaving the herds altogether (Creel and Winnie 2004).

Impacts of Wolves on Big Game Hunting

While each of the previously discussed studies provides insight into how wolves are affecting big-game herds, of more importance for the context of this thesis is how wolf predation translates into effects on big-game hunting opportunities. Hunter harvest rates, permits issued, average days to kill, as well as many other measures are each a function of the population of big-game in the region. As discussed previously, predation in some areas of Alaska has led to the close of hunting seasons for several years. Many preliminary estimates on the effects of wolf predation on big-game hunting in the NRMRA have been presented, but their accuracy has come under severe scrutiny.

Possibly the most criticized big-game hunting reduction estimates were reported in the final environmental impact statement of the reintroduction of the gray wolf to Yellowstone and Central Idaho (USFWS 1994, Final EIS). This statement was produced by the U.S. Fish and Wildlife Service (USFWS) and released in May of 1994. This report stated that the effects on hunter harvest of elk due to wolf predation were estimated to decrease by 2 percent to 30 percent in antlerless game harvest, with no reductions in antlered game harvest (USFWS 1994, Final EIS). In addition, no impact for hunter harvest was estimated to occur for other big-game species (USFWS 1994, Final EIS).

Drawing upon the previous comparison of British Columbia versus Sweden and Finland, moose hunters in British Columbia harvest 5 percent of the precalving moose population, whereas hunters in Sweden and Finland harvest 57 percent of the precalving moose population (Kay 1997, 19). The eleven-fold difference in harvest between the two areas provides us with one example of the long-term effects a high predator population can have on big-game hunting.

In the McGrath Area, as stated previously, and Nelchina Basin in Alaska, wolves coexist with grizzly bear and black bear. In the McGrath area the Alaska Department of Fish and Game (ADFG) has a harvest objective of 130 to 150 moose per year, which the department cites as a needed harvest for the local food supply. However, as of 2003, recent years' harvest levels have been about 80 to 90 moose per year (ADFG 2004, Questions and Answers about Moose, Wolves, and Bears in the McGrath Area). The department claims the decline in the harvest level is due to predation. It says enough calves are being born to increase the population, but wolves and bears are killing nearly

two-thirds of the moose calves within their first months of life (ADFG 2004, Questions and Answers about Moose, Wolves, and Bears in the McGrath Area).

As of 2005, there have been no studies presenting estimates of the impact the gray wolf is having on big-game hunting in the NRMRA. While the magnitude of the predation effects might not be as great as in the example above, knowing how the gray wolf is affecting big-game hunting in the NRMRA will prove useful to hunters, the hunting industry, and game agencies. Such estimates are the goal of this thesis.

CHAPTER 3

MODELS

Two models will be developed in this chapter to understand how hunters and game agency officials may respond to wolf predation on elk in Montana. First, a model of hunter demand will be constructed to analyze how hunters adjust to the wolf's impact on the elk hunting "market" in Montana. Second, a discussion of the structure and incentives of Montana Fish, Wildlife, and Parks (MFWP) will be undertaken. From this discussion a game agency model will be constructed to analyze how MFWP may manage elk permit numbers in response to wolves.

Model of Hunter Demand

In order to analyze the market for big-game hunting in Montana, a thorough examination of the market distributional mechanism for limited hunting permits must be undertaken. Random lottery systems are used by many states as a form of distribution for limited special hunting permits. Until 2003, in Montana, hunting rights for many species of big-game animals were allocated through this random lottery distributional scheme. The hunting permits allocate the property rights to hunt a specific species in a specific hunting district. In Montana, the permits for mountain goat, bighorn sheep, and moose allocate all of the hunting rights for each of these species in Montana. These special permits are also used as a supplement to the general hunting license for elk and deer in Montana to allocate more valuable limited opportunity hunts.

As analyzed by Barzel, when prices are not allowed to adjust in order to distribute a good, consumers will compete by queuing in order to obtain the good. Given consumers with equal time costs, the consumers with the highest values for the good would obtain it because they would be the ones willing to queue the longest to obtain the good (Barzel 1997). However, in markets where goods are not rationed by normal price mechanisms, and queuing in the sense described above is not allowed, does the market reach a state of equilibrium? And if it does reach a state of equilibrium, how is this equilibrium obtained? This is the problem observed in markets where a random lottery system is used as a form of distribution for a good.

Estimating the value of goods not distributed through market mechanisms has given rise to a number of methods by which to estimate the values of such goods. This section will introduce three main valuation techniques that have been used in the past to estimate the value of goods where prices are distorted. A discussion of the process of, potential problems and biases associated with, and the estimates produced by each method will also be provided.

The Contingent Valuation Method

One common method used to estimate the values people place on non-market goods and services is contingent valuation. Contingent valuation uses survey data to estimate the average willingness to pay by a population for some good or service. Davis conducted the first contingent valuation study in 1963 to estimate the benefits of goose hunting (Venkatachalam 2003). Since then the contingent valuation method has been frequently used in policy analysis and in estimating non-use values of goods and services.

Although contingent valuation surveys differ in some respects, a typical application of the method is as follows (Venkatachalam 2003). The researcher constructs a survey that is to be sent to a predetermined portion of the population that is to be or has been affected by a change in a policy. The survey is made up of specific information on the change in policy, questions that attempt to elicit the values of the change in policy, as well as additional questions used for statistical purposes in constructing covariate estimates of the survey responses. The construction of the survey has to be done carefully. The researcher has to be certain that all the information necessary for a respondent to give accurate answers is included in the survey. In addition, the particular payment vehicle must be described to the respondent. The payment vehicle typically used is the funding source already identified to be the source of revenue for the policy. Typical payment vehicles may be a sales tax, a property tax, donations, etc. Also, respondents may be asked to state values on an individual, or household basis as determined by the researcher as to which is the most applicable for the particular situation being evaluated (Venkatachalam 2003).

The three major response formats typically used in contingent valuation surveys are open-ended bidding, payment card, and dichotomous choice. Open-ended and payment card formats allow respondents an unconstrained bidding amount, while the dichotomous choice format, the most commonly used, provides respondents with a single bid amount which respondents can either accept or deny (Venkatachalam 2003).

Before the survey is conducted it is typically tested on focus groups. This pre-testing allows researchers to modify the survey in order to best suit the study and attempt

to eliminate potential biases. Once the survey is complete it is then conducted on the predetermined sample of the affected population. There are four main methods of data collection used in contingent valuation: mail, Internet, telephone, and personal interviews. Each method of collection provides the researcher with different strengths and weaknesses that allow the researcher to choose the best mode for the particular study at hand. In addition to being the cheapest, mail surveys are the most commonly used method of data collection and allow the researcher to provide each respondent with more information than allowed by the other modes. Once the response data is gathered and statistical analysis has been done, the values produced from the contingent valuation method are the average willingness to pay per individual, or per household (Venkatachalam 2003).

Using the contingent valuation method, Rosen (1997) found the average maximum willingness to pay per household for red wolf recovery in northeastern North Carolina to be $66.74. In addition, many researchers use data collected in the National Survey of Fishing, Hunting, and Wildlife to estimate hunting and fishing values of interest.

While contingent valuation (CV) is still used by many researchers, there are many potential problems and biases associated with contingent valuation that affect the validity, or accuracy, and reliability, or reproducibility of the CV results and attained values (Venkatachalam 2003).

One problem associated with using the CV method is determining the correct measurement of willingness-to-accept (WTA) or willingness-to-pay (WTP). Since 1946,

when Hicks developed the compensating variation and equivalent variation surplus measures, the debate has continued over which measurement of surplus should be used in policy analysis. The compensating variation measure refers to WTP for a welfare gain and WTA for a welfare loss (Venkatachalam 2003). The equivalent variation measure refers to WTA for a welfare gain, but WTP for a welfare loss. Determining which measurement is proper for the particular study at hand is an important issue for a researcher using the CV method because of the dramatic disparity in the results the chosen measurement may cause. The divergence in the values attained by using WTP versus WTA depends on the degree of the substitution effects associated with the good as well as the positive income elasticity, and can range from zero to infinity (Venkatachalam 2003). In addition, the divergence between WTP and WTA has also been attributed to property rights and transactions costs (Venkatachalam 2003). The transactions costs disparity arises because respondents WTP values exclude the transactions costs associated with attaining the good, while the WTA costs include the transactions costs associated with the good (Venkatachalam 2003). Empirical studies have found that for the same good the disparity between WTP and WTA can range from an upper bound of 61 times to a lower bound of 2.4 times difference in values (Venkatachalam 2003). Because of the disparity between WTP and WTA, as well as the debate over which is the proper measurement, the estimates produced by the CV method are vulnerable to much criticism. In the context of estimating the value of hunting permits, WTP would measure the amount a hunter would be willing to pay for a permit. WTA would measure the amount a hunter would be willing to accept to have a permit taken away from him.

Another problem associated with the CV method is the embedded effect. Some goods are valued as part of a larger package, or bundle of goods. Embedding occurs when a respondent reports the value of the larger package of goods together and not just the value of the good on its own (Venkatachalam 2003). The results of several studies suggest that the embedding problem is not only found in public goods, but private goods as well. Embedding usually occurs because of improper survey design and implementation, as well as other factors. To counter this problem a researcher can design the survey as to include information and follow-up questions in order to focus the respondents' attention on the smaller commodity being valued in order to minimize the potential error associated with the embedded effect (Venkatachalam 2003). The embedding effect is likely to occur in estimating hunting permit values because each hunting permit contains the rights to hunt in unique hunting districts that provide the permit holder with various hunt characteristics, including game and non-game populations, as well as harvest rates. Therefore, asking hunters the value of these permits would likely include the underlying value these district characteristics provide to the hunter, many of which a hunter could gain value from outside of holding the hunting permit.

Question order bias, or the sequencing effect, is another potential problem associated with the CV method. The sequencing effect occurs when the WTP values reported change with a differing order of questions. It occurs most often in multi-good valuation studies. The sequencing effect most often occurs because of improper survey design and can be limited by informing survey respondents about what they will be asked

to value before the WTP questions, as well as giving the respondents opportunities to make revisions on their bids before completing the survey (Venkatachalam 2003). Order bias might occur in using CV to estimate hunting permit values because there are various hunt characteristics and regulations associated with each permit, each of which might be valued differently depending on the order of placement in the survey.

Providing the correct information to survey respondents is crucial in conducting a CV study. However, when respondents are not provided with adequate information on the good they are asked to value, the stated values they provide might not be the actual values that the survey is intended extract (Venkatachalam 2003). When this occurs, information bias exists, thereby biasing the results of the study. In terms of estimating the wolf's impact on hunting permit value, respondents would have to be provided with all the correct information on how wolves impact game and non-game species in an area, as well as all relevant permit information, exclusion of which would create information bias.

Problems can also arise in each value elicitation technique that may be used in a CV study. As discussed earlier, the most commonly used elicitation techniques are open-ended bidding, payment card, and dichotomous choice. While each method has potential problems specifically associated with each technique, collectively there is starting point bias, range bias, centering bias, non-response bids, and strategic bias (Venkatachalam 2003). Another potential bias associated with the use of the CV method is hypothetical bias. Hypothetical bias arises when the payment method suggested to respondents or the good being valued diverges from "reality," or is simply that which the respondent is

unfamiliar. This however does not hold for those goods with which respondents are familiar with or with which are traded in markets (Venkatachalam 2003).

Perhaps one of the strongest criticisms of the CV method is with respect to strategic bias. Strategic bias occurs when an individual misstates their true value in order to sway the outcome of the study. Overpledging is the type of strategic bias that occurs from a respondent overstating his WTP value with the expectation that it will influence the outcome of whether the good is provided. Free riding is the type of strategic bias whereby a respondent understates his WTP value with the expectation that others would pay a sufficient amount for the good (Venkatachalam 2003). In terms of estimating the value impacts of wolves on big game hunting using CV, strategic bias could be the greatest potential problem facing a researcher because of the heated emotions surrounding the issue.

Despite the potential problems, the contingent valuation method has been used by many researchers to estimate the value of many non-market goods and services. In addition to the potential biases associated with the CV method, the estimates produced by such a method are themselves of limited use because they are average willingness to pay or maximum average willingness to pay. However, economists are more often interested in marginal values, not the average values produced by the CV method.

The Travel Cost Method

The travel cost method is another technique used to estimate use values of the environment. It is a demand-based model that uses observed trip expenses to a recreational site in order to estimate the total use value, or access value of one site, or

multiple sites. Travel cost models can be separated into two categories: single-site models and multi-site models. The basic theory behind the travel cost model is the application of the law of demand to trip distances. The farther an individual lives away from a site, the higher the travel cost of visiting the site and the lower the quantity demanded for site visits. On the other hand, the closer an individual lives to a particular site, the cheaper it is to visit the site, and many more visits will be demanded (Parsons 2003, 269).

Single-site travel cost models are used to estimate the demand for trips to a single recreation site by a person over a particular period of time (Parsons 2003, 271). The price is the total trip costs of reaching the site, and the quantity demanded is simply the number of visitations a person makes to a site over a season. In addition, the demand for a site is also a function of income, a number of demographic variables, and the price of substitute sites. The total trip costs include the sum of the individual's travel expenses necessary to make a trip possible. The trip costs may include, but are not limited to travel costs, access fees, equipment costs, and time costs. The measurement of time costs to an individual is most commonly estimated by a person's wage. However, many problems associated with time costs are encountered because many individuals visiting a site are retired, on paid vacation, are students, unemployed, or stay at home parents, thus using wages to estimate time costs could overestimate values tremendously. How to measure time costs, as well as which trip costs are included in a model is up to the discretion of the researcher (Parsons 2003, 286). Therefore the developed model is vulnerable to researcher subjectivity.

Other problems exist in handling multiple use sites. For example, a lake access might be used for swimming, fishing, boating, etc. In order to estimate the value the lake access provides to fisherman, a researcher must identify that an individual's primary purpose for visiting the site was for fishing. While a visitor might use the site for other purposes during a visit, the common practice is to classify the trip for its primary purpose (Parsons 2003, 275).

Modeling multi-purpose trips using the travel cost method is much more difficult than modeling single-purpose trips (Parsons 2003, 270). The most commonly used multiple site travel cost model is the random utility maximization model (RUM) (Parsons 2003, 270). The RUM is much more complex than the single site models and will not be covered in depth in this section. It is important to point out that the RUM is the most widely used travel cost model. In addition to accounting for the variables in the single-site model, it also accounts for the site characteristics as well (hunting success rate, catch rate of fish, etc.). Although requiring much more data than the single-site models, the RUM models allow researchers to account for a wide array of substitutes, changes in access quality variables, as well as many other economically important issues (Parsons 2003, 270).

While the models used in the travel cost method continue to progress, three main problems exist with using this method to estimate use values of a resource. First, the results obtained from the travel cost method are, as in the contingent valuation approach, average willingness to pay for a particular site. Thus, the results obtained from this method are of limited use. Also, the travel cost method credits the entire trip cost to the

value of the site itself. However, the trip itself might provide an individual with value, so crediting this value to the actual site will misrepresent the value an individual places on the site. Finally, the model used to estimate a site's value is subjective. The decision to include, or exclude, determine the "primary" purpose for a visit, etc. is dependent on the decision of the researcher. Avoiding this type of subjectivity, and allowing the data to speak for itself is vital in obtaining unbiased results (Parsons 2003, 270).

Scrogin, Berrens, and Bohara (2000) used the travel cost method to estimate the welfare effects of policy changes in New Mexico designed to increase resident participation in elk hunting permit lotteries. The models, constructed accounting for the uncertainty associated with lottery participation, estimated a 24.2 percent increase in consumer surplus due to the policy changes undertaken in New Mexico (Scrogin, Berrens, and Bohara 2000).

Fix and Loomis used the travel cost method to infer the value visitors receive from the numerous mountain biking trials in Moab, Utah. The data was used to construct a demand curve for Moab mountain biking trails and estimate consumer surplus. The study estimated that users gained $197 to $205 per trip in consumer surplus (Fix and Loomis, 7).

The Hedonic Method

When analyzing the market for big-game hunting permits, the average values produced by the contingent valuation and travel cost methods do not provide the marginal values needed for proper examination of the market. The hedonic method for non-market

valuation provides marginal values of the underlying hunting characteristics implicitly held in the value of a given hunting permit.

The hedonic method uses market transactions for differentiated goods to value the characteristics of the good and this method can be applied to evaluate limited hunting permits distributed through non-market mechanisms (Taylor 2003, 331). Each permit holds unique characteristics that, if obtained, it provides to the holder of the permit. Various levels of queuing are also observed. With different levels of queuing, or "prices," for each permit, using the hedonic method allows us to infer the value the marginal applicant would receive from holding the rights to such a permit.

The main advantage the hedonic method holds over each of the previously discussed valuation methods, is that it uses observable behavior in order to estimate the marginal value of a good (Taylor 2003, 332). Inferring values from observable behavior prevents the misrepresentation of values and expenses that plague the previous methods discussed.

Other studies using similar approaches as those of this thesis have used this method to estimate the marginal values that hunting permit characteristics provide to hunters. Buschena, Anderson, and Leonard (2001) used the hedonic method to estimate the marginal values applicants for Colorado's limited elk hunting permits received from various hunting characteristics. Using Ordinary Least Squares, they found positive and significant coefficients for the variables measuring private access, special weapons restrictions, higher harvest success rates and early season hunts. The results suggest that an increase in the desirable characteristics of the permit increases the value of the permit

to the marginal hunter. In addition, they found negative and significant coefficients on the harvest restriction and number of permits issued in a given district (Buschena, Anderson, and Leonard 2001).

Taylor and Marsh (2003) also used the hedonic method to estimate the value of characteristics of transferable deer hunting permits in Kansas. They used their data to quantify the effects of socioeconomic characteristics, demographic and spatial variables, as well as permit attributes on the price of a transferable deer hunting permit (Taylor and Marsh 2003).

The Attributes of Limited Hunting Permits

The attributes of each hunting permit differ in two categories, their regulations and their characteristics. Each permit has a number of regulations that accompany the property rights of the permit. First, each permit limits a hunter to hunt within a specific hunting district, or stated districts. Also, each permit typically limits a hunter to harvest one animal, but with additional harvest restrictions. There are three basic permit categories for elk in Montana: either-sex, bull-only, and cow-only. The either sex permits are the only unrestricted sex harvest permits, while the bull-only and cow-only permits allow permit holders to harvest the designated sex. Additional harvest restrictions on antler size for bull-only and either-sex permits may be enforced as well. These restrictions require a bull to have a minimum antler size in order for a permit holder to harvest the animal (MFWP Big-Game Hunting Regulations 2001).

Each permit is only valid within a set time period, or season. Other restrictions may designate a specific hunting area, or weapons restrictions. Weapons restrictions limit

hunters to using only certain categories of weapons, such as archery-only, primitive weapons only, rifle, etc. (MFWP Big-Game Hunting Regulations 2001).

The second set of attributes that hunting permits define are its hunting characteristics. Each year Montana Fish, Wildlife, and Parks (MFWP) releases the hunting and harvest information for the previous year's permit recipients (MFWP Elk Hunting and Harvest Report 2001). The information in this report includes the number of permits issued, the number of applicants, the number of hunters, the percent success of harvesting an animal, the average days to kill, the number of animals harvested, and the make up of the harvest. The make up of the harvest includes the number of bulls, cows, and calves harvested under each permit type. Also, the number of permits issued divided by the number of applicants represents the probability of being drawn for a given permit in the previous year. Hunters are provided with all of the previous year's data, which gives them an estimate of the hunting characteristics that they will receive from a given permit (MFWP Elk Hunting and Harvest Report 2001).

Other characteristics that each permit defines are the attributes of the designated hunting districts. Each district differs in landscape, herd quality, ease of access, and proximity to a major population center, as well as many other area specific features. Some of these attributes may provide hunters with additional value. All else equal, two areas with equal permit regulations and harvest characteristics, but different district attributes, will provide a hunter with differing values. Partial information about herd quality is available from the Boone and Crockett Club (BCC) record books. This data provides hunters with the score of each bull registered with the BCC, and the county in

which it was killed (BCC 2004). The information from this and other record books is an indicator of the antler quality of the herd within a certain area.

Applicants for hunting permits place value on each permit as a function of the permit's stated attributes. All else constant, increases in the positive characteristics of a permit are expected to generate a higher value to applicants for the permit. As analyzed by Nickerson, holding characteristics constant, the more regulations placed on a permit, the lower value the permit has to permit applicants (Nickerson 1990). The goal of this chapter is to analyze how hunters compete for these differentiated permits, and how equilibrium is attained.

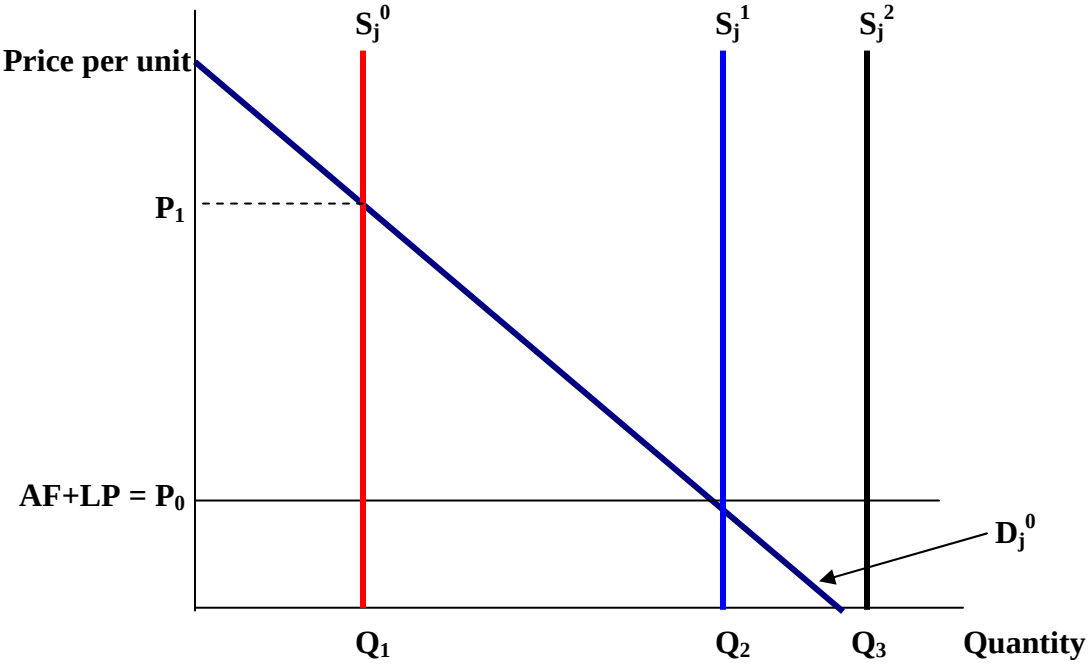
The Market for Limited Hunting Permits

The primary market for hunting permits does not reach equilibrium in prices. The demand for a given hunting permit (*QD*), permit *j* (where *j* is the permit number), can be constructed as a function of the prices associated with obtaining permit *j* ($\underline{p}$), characteristics of permit *j* ($\underline{c}$), and the regulations of permit *j* ($\underline{r}$). The demand for permit *j* can be written:

(1) $QD_j(\underline{p}, \underline{c}, \underline{r})$.

Consider demand D_j^0 in figure 3.1. The supply of permit *j* is set by MFWP based on area biological studies, as well as constituency pressure from hunters. The supply is represented by a vertical line (S_j^0, S_j^1, or S_j^2 in figure 3.1), and is fixed at the pre-announced quota level. If the quota were set at Q_1, the observed supply curve would be S_j^0. If the price was allowed to adjust to clear the market, Q_1 would be purchased at a price of P_1, and the market would reach equilibrium.

Figure 3.1. Market supply and demand for hunting permit *j*.



However, the price of each hunting permit is not allowed to adjust. The price a hunter pays for a permit is made up of a non-refundable application fee plus the license price, represented by $AF + LP = P_0$ in figure 3.1. At a price fixed at P_0, a shortage exists and is equal to the difference between the quantity supplied, Q_1, and the quantity demanded, Q_2. From Barzel (1997) we know that the market might clear by consumers competing for the good by queuing (Barzel 1997). If hunters were allowed to wait in line to attain a permit, Q_1 would be purchased at a price of P_1, with P_0 being paid in monetary units, and P_1 minus P_0 being paid in the form of time costs.

Two other allocation scenarios might also be observed in this market. If the quota level were set at Q_2, with a fixed price of P_0, we would observe the market reaching equilibrium in prices. If the quota level were set at Q_3, with a fixed price of P_0, a surplus of Q_3 minus Q_2 exists and the market reaches equilibrium at Q_2. While both of the last

two situations are common for some cow-only elk permits, it is very rare for the either-sex or bull-only elk permits to be in a market clearing in price, or surplus situation.

Market Clearing under a Random Lottery

In the situation described in the previous section either prices or queuing was the mechanism by which the market was able to reach equilibrium. However, the problem observed in the market for limited hunting permits is that price adjustment and queuing are not allowed in order for the market to reach a state of equilibrium in price. Given that supply is set at Q_1, and demand is D_j^0, with a fixed price of P_0, can the above market reach equilibrium? The nature of this equilibrium and how it is attained will be the focus of the rest of this section.

A brief discussion of a method developed by Peter Nickerson (1990) will be undertaken to justify the means by which demand will be measured in this section. Peter Nickerson's article, "Demand for the Regulation of Recreation," analyzed the random lottery distribution system used in Washington State in order to estimate the demand for the regulation of hunting by the state game agency. Nickerson developed a model to infer the value of a given hunting permit, permit *j*, to the marginal hunter using the number of applicants for a permit and the number of permits issued, as well as a number of other variables. The value of permit *j*, V_j, is a function of income (Y), prices (P), household characteristics (H), and permit characteristics (q). Let the supply of permit *j* be S_j, and the number of entrants in the lottery for permit *j* be N_j. Therefore, S_j/N_j represents the probability of being drawn and receiving permit *j* to a lottery entrant. Also, let the non-refundable fee associated the lottery for any permit be P_L (Nickerson 1990).

The expected value of entering the lottery for permit *j* and being drawn can be written as $(S_j/N_j)(V_j - P_L)$. The expected value of entering the lottery for permit *j* and not being drawn is $-[1-(S_j/N_j)](P_L)$. Therefore, the expected value of entering the lottery for permit *j*, $E(L_j)$, can be written as the sum of the values of its outcomes weighted by their likelihoods:

(2.2) $E(L_j) = (S_j/N_j)(V_j - P_L) - [1-(S_j/N_j)](P_L) = (S_j/N_j)(V_j) - P_L$.

An individual will choose to enter a lottery as long as $E(L_j) > 0$, and the expected value of entering the lottery for permit *j* is greater than the expected value of entering the lottery for any other permit (Nickerson 1990).

The data Nickerson used to analyze how regulations affect the demand and expected value of a permit are from the Washington State limited hunting licenses for elk and deer. He found that, controlling for other factors, weapons and elk gender restrictions negatively affect the value and demand for a permit. However, the negative effect of the antlerless only restriction was insignificant (Nickerson 1990). Nickerson's method for analyzing random lotteries provides a useful tool in estimating values of goods distributed through this mechanism and it will be the method used in the estimation section of this thesis. For a further discussion of lottery entrant expectations and adjustments see Appendix A.

Game Agency Model

MFWP manages and regulates hunting of big-game animals in Montana. Therefore, the management and regulatory approach taken by MFWP may have a significant impact on variables likely to be impacted by wolves. Because of this, MFWP might be able to exert some measure of control over how the impacts of wolves are passed on to big-game hunters in the state.

For example, if wolf predation within a hunting district is leading to elk population declines, MFWP may choose to maintain hunting permit numbers within that district, and hunters will likely experience lower harvest rates and higher average days to kill. On the other hand, if MFWP policy is to maintain high harvest rates and lower average days to kill, the alternate policy would be to reduce the number of permits issued in order to maintain these desired hunt characteristics. In addition, MFWP may choose to relax hunting regulations and allow hunters more advantages in harvesting an animal. For example, if wolf predation is leading to declining elk populations within a district, MFWP may increase the number of season days, or relax weapons restrictions in order to maintain high harvest rates. Because the response of MFWP may impact how hunters are affected by the predation impacts of wolves, the models developed in this thesis account for the control MFWP has upon the market for big-game hunting in Montana.

Although the United States Fish and Wildlife Service (USFWS) currently manages wolves, it is also useful to consider the incentives MFWP might have over wolf management if control was to be handed over to the state. As noted in a previous section, wolf management is supposed to be passed to the state agency once the gray wolf in the

NRMRA is downgraded from endangered to threatened, and all three states in the NRMRA receive approval of wolf management plans by the USFWS. The wolf was downgraded to threatened in 2003, but Wyoming's wolf management plan has not been approved by the USFWS as of April 2005.

In order to understand how MFWP might manage wolves, it is important to understand the underlying incentives MFWP has as a regulatory agent. Parker (2001) found that wildlife agency budget structure and organization are key determinants in agency behavior. Parker used state game agency data on budget size, hierarchal structure of the agency, scope of the agency, funding sources, constituency variables, and other variables to determine the agency's budget allocations toward game and non-game animals (Parker 2001). Specific findings that have bearing on the analysis in this thesis are that the more general funds an agency receives, the higher is its budget allocation toward non-game. Parker also found that increases in the number of hunters leads to increased budget size (Parker 2001). In addition, increases in the total number of hunting days leads to decreases in non-game budget allocation, while increases in wildlife watching days leads to increases in budget size and allocation towards non-game (Parker 2001).

Parker's findings provide useful determinants of MFWP's incentives in game management generally, and also extend to the agency's future approach to wolf management. To evaluate how Parker's findings correspond to MFWP's current and future responses to the wolf's presence within Montana, this section will provide a description of MFWP's agency organization, budget structure, agency scope, and the

constituent pressures exerted on MFWP. Understanding the incentives MFWP has as a regulatory agent, in addition to the stated objectives of MFWP, will allow us to set up a direct objective function for the agency.

Structure and Objectives of Montana Fish, Wildlife, and Parks

Montana Fish, Wildlife, and Parks is the state agency responsible for management of Montana's wildlife, fisheries, and state parks. MFWP is structured into eight different divisions under the MFWP chief of staff. The divisions include: Responsive Management, Fisheries Division, Wildlife Division, Parks Division, Enforcement Division, Conservation Education Division, Legal Unit, and River Management (Inside of Montana Fish, Wildlife, and Parks, www.fwp.state.mt.us).

Funding from MFWP comes from four major sources. The majority of the funding received by MFWP comes in the form of hunting and fishing license revenue. In 2003, hunting and fishing license revenue supplied 57 percent of the agency's funding (MFWP 2004, Annual Report 2003). The second largest funding source for the agency in 2003 was federal revenue. This source of funding is comprised of federal funds received by MFWP from the Federal Aid in Sport Fish and Wildlife Restoration Programs, tax revenue received from arms, ammunition, and particular archery equipment, tax revenue received from fishing equipment, the land and Water Conservation Fund, and import duties collected from boats and fishing tackle. Federal revenue supplied MFWP with 29 percent of the agency's budget (MFWP 2004, Annual Report 2003).

The third source of revenue for MFWP is state funds. These funds are collected through state park fees, a state fuel tax, a lodging facilities tax, as well as other sources

(MFWP 2004, Annual Report 2003). State revenues supplied MFWP with 12 percent of the agency's budget in 2003. The forth source of revenue for MFWP is private revenue received by the agency, but these private contributions were only 2 percent of the agency's budget in 2003 (MFWP 2004, Annual Report 2003).

Management of wildlife, fisheries, and state parks requires consideration of a number of environmental and political factors. Wildlife management includes setting hunting seasons and permit numbers, establishing hunting regulations, addressing human-wildlife conflicts, conducting annual population surveys, and enforcing regulations. Managing fisheries includes setting fish limits, stocking, managing hatcheries, and enforcement of regulations. State land management includes providing access to state lands, setting access regulations, maintenance, and enforcement of regulations (MFWP 2004, Annual Report 2003).

MFWP manages wildlife by employing a variety of different techniques and balances conflicting constituency support. Montana's wildlife is a common property resource that provides many different user groups with value, some of which have conflicting uses of the resource. For example, hunters gain value from viewing different species of wildlife, the existence value of the wildlife, and from harvesting an animal. However, while harvesting an animal provides one hunter with value, harvesting an animal also decreases the opportunity another person has of viewing or harvesting that species of wildlife. In addition, knowing that particular species of wildlife is being harvested in an area might decrease some individual's existence value obtained from that animal.

There are three main categories of demanders of MFWP: Hunters, Recreationists, and Anglers. Hunters are defined as those who gain value from hunting activities in Montana. Anglers are defined as those who gain value from fishing activities in Montana. Recreationists are defined as those who take part in any other outdoor activity in Montana. Examples of recreationists are kayakers, hikers, wildlife watchers, and etcetera. However, individuals are not restricted to one group. In Montana, a given individual might be a hunter, recreationist, and angler, thereby gaining utility from each activity at different points throughout the year.

In addition, the particular activities of an individual participating in one group might affect the value they receive from participating in another group. For example, suppose an individual gains utility as a hunter by harvesting an animal and a recreationist by viewing an animal. An individual participating in hunting might harvest an animal, thereby gaining utility from the harvest. However, harvesting the animal as a hunter might decrease the chance of the individual to gain utility as a recreationist in viewing that species while participating in a recreation activity. The individual will choose to harvest the animal if he gains more marginal utility from harvesting the animal in the hunting activity than he would from the marginal value he would receive from the increased probability of viewing the particular species of animal that the harvested animal provides. The individual always chooses, considering these trade-offs, the greater valued activity, or action. However, if the hunter chooses not to harvest the animal another hunter may. Therefore, the individual might choose to harvest the animal even if the

marginal value he would obtain from the animal in recreation activities is lower than the marginal value he would receive from harvesting the animal as a hunter.

An additional conflict arises in the form of predators, and in particular for the interests of this thesis, the gray wolf. The existence of predators impacts the values individuals receive from wildlife in a number of different ways. First, recreationists and hunters might place an existence value, whether positive or negative, on knowing that predators inhabit areas of Montana. Second, both groups might place a value on the opportunity to view a predator in the wild. However, predators prey on wildlife that hunters and recreationists both value. Therefore, increasing predator numbers lowers the values both hunters and recreationists receive from other forms of wildlife. The conflicting interests concerning predators in and among the different constituencies of MFWP complicate the management practices and trade-offs that must be decided upon by MFWP officials.

As of 2005, wolf management is still under control of the USFWS. Therefore, MFWP must currently take the impacts of wolves within the state as exogenous. However, if wolf management is passed on to MFWP, the agency will have to decide how to manage wolves in Montana. The trade-offs between the values that wolves provide MFWP's constituency base and the values that wolves take from constituencies must be balanced when MFWP is given control of wolf management. Another important consideration is the wolf's effect on MFWP budget. As mentioned earlier, MFWP receives most of their budget from hunters and anglers. Therefore, the wolf's impact on hunters might potentially affect the revenue MFWP receives from hunting licenses.

Because of the additional importance of hunters for MFWP, their interests in state wolf management will most likely be given greater weight than the interests of recreationists.

Montana's wolf management plan, which was accepted by the USFWS in 2003, is to manage wolves at the minimum allowable level of fifteen breeding pairs (MFWP Final EIS 2003). However, since a breeding pair is only two wolves, MFWP may be able to exert intensive management on pack sizes under this plan. The larger the pack size, the more predation on game populations and the more likely are livestock-wolf conflicts. Therefore, in the future MFWP is likely to have the incentive to manage wolves not only at the minimum allowable level of breeding pairs, but also at relatively small pack sizes as to limit their impact upon hunting revenue sources as well as support.

Additional pressure to manage pack sizes at low levels might also come from a fourth constituency group, agricultural interests. From 1987 to 2003, at least 155 cattle, 318 sheep, 22 dogs, and 9 other farm animals have been killed by wolves within Montana (USFWS 2004, 2003 Rocky Mountain Wolf Recovery Report). During that same time period, 96 wolves were moved and 127 were killed because of wolf-livestock conflicts. Livestock are generally easy animals for predators to kill. Once a wolf learns the ease of livestock predation, it is difficult to break the wolf of the behavior. Such wolves are either captured and relocated, or killed to avoid further predation of livestock. In the past, due to the gray wolf's endangered status, ranchers were compensated the market price of their wolf killed livestock from a fund operated by Defenders of Wildlife. However, these payments to ranchers are not to continue into the future under the current policy of Defenders of Wildlife. While ranchers will have more freedom to guard their livestock if

wolves are placed under state management, there is currently no compensation fund planned for losses by ranchers from wolf predation. Agricultural interests are a strong political force in Montana and the uncompensated losses to ranchers are likely to be addressed politically. This additional political pressure against wolves will also add to the incentives of MFWP to manage wolves at low pack sizes in order to minimize wolf-livestock conflicts.

Game Agency Support

The number of wolves is presently determined exogenously to MFWP. Given their constituency base and budget source, MFWP has to determine how many of their resources to dedicate to each management activity, and how to manage each activity. One of the stated goals of MFWP is to "equitably balance the interests of hunters, anglers, and other outdoor recreationists, visitors to historic sites, landowners, the public and the needs of Montana's fish, wildlife and parks resources" (MFWP, Vision, Mission, & Goals). Therefore, the constituent support function *S*, is written as a function of hunter support (*H*), recreationist support (*R*), and angler support (*A*). This section will contain a generic analysis of the game agency model and discuss the ways in which the wolf variables may impact the support function of MFWP. In addition, a simplified agency model will be constructed in order to gain a useful comparative statics result.

As discussed previously, there are many variables that impact hunter demand, and thus the surplus, or value hunters receive from hunting, as well as the revenues MFWP receives from the sale of hunting licenses. Therefore, the hunter support function (*H*) in period *t* is written as a function of the hunting district specific variables ($\underline{d}_t$) that impact

hunter demand $\left(H_t\left(\underline{d}_t\right)\right)$. The hunting district specific variables in the vector $\underline{d}_t$ include; the number of permits issued, license prices, hunting regulations, hunt characteristics, game population, wolf population, and other non-game wildlife populations for all Montana hunting districts.

As with hunter support, there are many driving factors behind recreationist demand, and thus the value constituents receive from recreation activities, as well as the revenue and political support MFWP receives from recreationists. Therefore, the recreationist support function (R) is written as a function of the variables ($\underline{r}$) that impact recreationist demand $\left(R_t\left(\underline{r}\right)\right)$. The variables in the vector $\underline{r}$ include; land access, land quality, game populations, wolf population, other non-game populations, water access, and water quality.

Anglers are another important constituency of MFWP. Angler support (A) is written as a function of the variables ($\underline{a}$) that impact angler demand, and thus the value constituents receive from fishing in Montana, as well as the license revenues MFWP receives from the sale of fishing licenses $\left(A_t\left(\underline{a}\right)\right)$. The variables in the vector $\underline{a}$ include; water access, water quality, fish population, and fish quality.

Simplified Game Agency Model

Due to its complexity, no useful comparative statics could be gained from a general game agency model. For further discussion of the general game agency model see Appendix B. Simplifying a general game agency model in a number of ways allows useful comparative statics to be obtained without greatly compromising the underlying

incentive structure of the agency support function (S). First, because angler support is not likely to be impacted by wolves, the angler support function will not be included in this discussion. Also, the model can be simplified to a two district model, with only one district inhabited by wolves. Therefore, constituent support is written as a function of hunter support (H_t) and recreationist support (R_t) in period t, as well as hunter support (H_{t+1}) and recreationist support in period $t+1$ (R_{t+1}). As discussed previously, hunter support is likely weighted differently than recreationist support. Therefore, hunter support and recreationist support are adjusted for this effect by α_1 and α_2 respectively. The constituency support functions for period $t+1$ are discounted by β.

Assume for this discussion that wolves move into a district in Montana during period t, with the full knowledge of MFWP prior to setting hunting permit numbers. In this simplified analysis elk are the only game animal considered. Also, since year t is the first year wolves are assumed to inhabit Montana hunting districts, assume wolves in period t have not affected game populations enough to limit wolf numbers in period $t+1$ or to have reduced the game population enough to impact hunting values in period t. These assumptions allow wolves in period $t+1$ to be written only as a function of wolves in period t (w_t). The wolves in period t are modeled to only affect hunter values through existence and viewing values and distributional effects on the elk population. Other variables likely impacting elk and wolf populations (i.e. weather variables) will also be excluded from this simplified model. To further simplify the analysis, assume that adjusting the number of elk permits issued is the only management strategy MFWP can employ to counter predation impacts by wolves. Also, assume that the number of elk

harvested in period *t* do not impact the elk population until period *t+1*. Lastly, since other district specific variables that affect hunter values will likely be unaffected by wolves they will not be included in the model

Hunter support in period *t* (H_t) is written as a function of the sum of the two districts' per hunter permit values (V_{jt}) multiplied by the number of permits issued (i_{jt}). Constructing the hunter support function in this linear manner allows for the market forces previously discussed to be included in the model without a constraint that would necessarily contain wolves, allowing useful comparative statics to be obtained. The per hunter value in district *j* is written as the population of elk (e_{jt}), the number of permits issued (i_{jt}), and the number of wolves (w_{jt}). For simplicity, assume that district *i's* elk population in period *t* is given as an endowment of elk. The harvest rates hunters experience in period *t* are implicitly held in the support function in the elk population, the wolf population, and the number of permits issued variables. Recreationist support in period *t* (R_t) is written as a function of the hunting districts' elk populations (e_{it}) and the number of wolves (w_{it}) in district *i*.

As modeled for period *t*, hunter support in period *t+1* (H_{t+1}) is written as a function of the districts' elk population (e_{it+1}) and the number of wolves (w_{it+1}) in period *t+1*. The elk population in period *t+1* is written as a function of the endowment of elk in period *t*, the number of wolves in period *t*, and the number of permits issued in period *t*. The values hunters receive from the number of permits issued in period *t+1* is implicitly held in the elk population in period *t+1* and so these permits are abstracted from the hunter support function in period *t+1*. Recreationist value in period *t+1* is also written as

a function of the sum of the hunting district *j*'s elk population (e_{jt+1}), and the number of wolves (w_{jt+1}) in period *t+1*.

From the factors discussed above a simplified direct objective function can be constructed. The direct objective function of MFWP (*S*) is shown in equation (3.1).

$$\max S = \begin{bmatrix} \alpha_1 i_{1t} \bullet V_1\left(e_{1t}, i_{1t}, w_{1t}\right) + \alpha_1 i_{2t} \bullet V_2\left(e_{2t}, i_{2t}\right) \\ +\alpha_2 R_t\left[e_{1t}, w_{1t}, e_{2t}\right] \\ +\alpha_1 \beta H_{t+1}\left[e_{1t+1}\left\{e_{1t}, w_{1t}, i_{1t}\right\}, w_{1t+1}(\bullet), e_{2t+1}\left\{e_{2t}, i_{2t}\right\}\right] \\ +\alpha_2 \beta R_{t+1}\left[e_{1t+1}(\bullet), w_{1t+1}(\bullet), e_{2t+1}(\bullet)\right] + \varepsilon \end{bmatrix} \tag{3.1}$$

The first order conditions of the direct objective function are shown in equation (3.2). At the optimal choice variables the value of each equation in (3.2) is zero.

$$\frac{\partial S}{\partial i_{1t}} = \alpha_1\left(V_{1t}(\bullet) + i_{1t}\frac{\partial V_{1t}(\bullet)}{\partial i_{1t}}\right) + \beta\left(\alpha_1\frac{\partial H_{t+1}(\bullet)}{\partial e_{1t+1}} + \alpha_2\frac{\partial R_{t+1}(\bullet)}{\partial e_{1t+1}}\right)\left(\frac{\partial e_{1t+1}(\bullet)}{\partial i_{1t}}\right) = 0$$

$$\frac{\partial S}{\partial i_{2t}} = \alpha_1\left(V_{2t}(\bullet) + i_{2t}\frac{\partial V_{2t}(\bullet)}{\partial i_{2t}}\right) + \beta\left(\alpha_1\frac{\partial H_{t+1}(\bullet)}{\partial e_{2t+1}} + \alpha_2\frac{\partial R_{t+1}(\bullet)}{\partial e_{2t+1}}\right)\left(\frac{\partial e_{2t+1}(\bullet)}{\partial i_{2t}}\right) = 0 \tag{3.2}$$

If the Implicit Function Theorem holds, then the optimal number of permits issued for both districts ($\underline{i}^*$) can be obtained and written as a function of the exogenous variables in the model. By plugging the $\underline{i}^*$s into the first order conditions an identity is obtained. Differentiating these first order conditions with respect to wolves and using Cramer's Rule provides comparative statics results for $\left(\frac{\partial i^*_{1t}}{\partial w_{1t}}\right)$ and $\left(\frac{\partial i^*_{2t}}{\partial w_{1t}}\right)$. The Cramer's Rule result for $\left(\frac{\partial i^*_{1t}}{\partial w_{1t}}\right)$ is shown in equation (3.3). Similarly, the result for

$\left(\frac{\partial i^{*}_{2t}}{\partial w_{1t}}\right)$ is shown in equation (3.4). S_{11} and S_{22} denote the second derivatives of the support function with respect to i_{1t} and i_{2t}, which by the conditions for maximization can both be signed as negative. The other terms contained in equations (3.3) and (3.4) are shown in equations (3.5) through (3.7). The H term in these equations denotes the Hessian matrix, the determinant of which is positive in this two-variable case.

$$(3.3) \quad \frac{\partial i^{*}_{1t}}{\partial w_{1t}} = \left(\frac{1}{|H|}\right)\left(-A_1 S_{22} + S_{12} A_2\right)$$

$$(3.4) \quad \frac{\partial i^{*}_{2t}}{\partial w_{1t}} = \left(\frac{1}{|H|}\right)\left(-S_{11} A_2 + A_1 S_{21}\right)$$

In equations (3.3) and (3.4),

$$(3.5) \quad S_{12} = S_{21} = \beta\left[\alpha_1 \frac{\partial^2 H_{t+1}}{\partial e_{1t+1}\partial e_{2t+1}} + \alpha_2 \frac{\partial^2 R_{t+1}}{\partial e_{1t+1}\partial e_{2t+1}}\right] \bullet \left[\frac{\partial e_{2t+1}}{\partial i_{2t}} \bullet \frac{\partial e_{1t+1}}{\partial i_{1t}}\right]$$

$$(3.6) \quad A_1 = \begin{bmatrix} \alpha_1\left(\frac{\partial V_{1t}}{\partial w_{1t}} + i_{1t}\frac{\partial^2 V_{1t}}{\partial i_{1t}\partial w_{1t}}\right) \\ +\beta\left[\alpha_1 \frac{\partial^2 H_{t+1}}{\partial e^2_{1t+1}} + \alpha_2 \frac{\partial^2 R_{t+1}}{\partial e^2_{1t+1}}\right] \bullet \left[\frac{\partial e_{1t+1}}{\partial i_{1t}} \bullet \frac{\partial e_{1t+1}}{\partial w_{1t}}\right] \\ +\beta\left[\alpha_1 \frac{\partial^2 H_{t+1}}{\partial e_{1t+1}\partial w_{1t+1}} + \alpha_2 \frac{\partial^2 R_{t+1}}{\partial e_{1t+1}\partial w_{1t+1}}\right] \bullet \left(\frac{\partial w_{1t+1}}{\partial w_{1t}} \bullet \frac{\partial e_{1t+1}}{\partial i_{1t}}\right) \\ +\beta\left(\alpha_1 \frac{\partial H_{t+1}}{\partial e_{1t+1}} + \alpha_2 \frac{\partial R_{t+1}}{\partial e_{1t+1}}\right) \bullet \left(\frac{\partial^2 e_{1t+1}}{\partial i_{1t}\partial w_{1t}}\right) \end{bmatrix}$$

$$(3.7) \quad A_2 = \begin{bmatrix} \beta\left[\alpha_1 \frac{\partial^2 H_{t+1}}{\partial e_{2t+1}\partial w_{1t+1}} + \alpha_2 \frac{\partial^2 R_{t+1}}{\partial e_{2t+1}\partial w_{1t+1}}\right] \bullet \left(\frac{\partial w_{1t+1}}{\partial w_{1t}} \bullet \frac{\partial e_{2t+1}}{\partial i_{2t}}\right) \\ +\beta\left[\alpha_1 \frac{\partial^2 H_{t+1}}{\partial e_{2t+1}\partial e_{1t+1}} + \alpha_2 \frac{\partial^2 R_{t+1}}{\partial e_{2t+1}\partial e_{1t+1}}\right] \bullet \left(\frac{\partial e_{1t+1}}{\partial w_{1t}} \bullet \frac{\partial e_{2t+1}}{\partial i_{2t}}\right) \end{bmatrix}$$

In order to sign the comparative statics in equations (3.3) and (3.4) the terms contained in the right hand side of equations (3.5) through (3.7) must be signed first. The remainder of this section will discuss the expected values of the right hand side terms and thus the expected signs of the comparative statics in equations (3.3) and (3.4).

Wolves in period *t* impact per hunter value through predation effects and existence value effects. In this model, the only predation impact of wolves in period *t* is through the distributional effects wolves have on the elk population. As noted in Chapter 2, when wolves are present, elk break up into smaller herds and tend to stray from cover less frequently. These distributional effects are likely to affect hunter harvest success rates in many ways, the sum of which is unknown. In addition, the existence and viewing value of wolves within a hunting district might increase or decrease per-hunter permit value. For example, if a hunter views a wolf while on a hunt he could gain value from viewing the wolf, or viewing the wolf could signal to the hunter that another predator has ruined his hunt. Due to these conflicting impacts of wolves on per hunter value no definitive sign can be determined for $\frac{\partial V_{1t}}{\partial w_{1t}}$. However, if the distributional, viewing, and existence values from wolves have a total affect that is negative, then $\frac{\partial V_{1t}}{\partial w_{1t}}$ is negative.

The number of permits issued affects per hunter value in various ways. First, many hunters gain value from hunting in areas with very few people. A higher number of permits issued translates into higher hunter numbers within a district, thereby reducing the value each individual permit holder gains. In addition, increases in the number of permits issued likely reduces the harvest rates obtained by hunters, decreasing the per

hunter value of the permits. Therefore, a marginal increase in the number of permits issued reduces the per hunter value of the permits, so $\frac{\partial V_{jt}}{\partial i_{jt}}$ is expected to be negative. If the effects of wolves in period *t* increase (decrease) hunter values, then an increase in the number of wolves at the margin will reduce(increase) the impact of a marginal increase in the number of permits issued on per hunter value, thus the sign of $\frac{\partial^2 V_{jt}}{\partial i_{jt} \partial w_{jt}}$ is expected to be negative (positive).

Elk in period *t+1* affect hunter and recreationist values in many ways. A higher elk population provides hunters with higher harvest rates, existence value, and viewing value. Recreationists also gain value from elk through viewing and existence values. Therefore an increase in the elk population at the margin will increase both hunter and recreationist support, so $\frac{\partial H_{t+1}}{\partial e_{jt+1}}$ and $\frac{\partial R_{t+1}}{\partial e_{jt+1}}$ are both expected to be positive. However, it is likely that the elk population in period *t+1* exhibits diminishing marginal support to the agency, meaning that $\frac{\partial^2 H_{t+1}}{\partial e_{jt+1}^{\ 2}}$ and $\frac{\partial^2 R_{t+1}}{\partial e_{jt+1}^{\ 2}}$ are both expected to be negative. Another important issue is how the marginal support an additional elk at the margin provides to the agency changes with a change in the wolf population. Elk in period *t+1* affect the value of issued permits in *t+1* as well as the harvest rates of *t+1* permit holders. The existence value and viewing value of an additional wolf at the margin might increase or decrease permit value in *t*+1 depending on how hunters value these effects. Also, because the initial elk distributional effects of wolves were incurred in period *t*, it is likely that a

marginal increase in the wolf population in period *t+1* would minimally effect elk distribution in period *t+1*. The conflicting elk distributional effects, viewing values, and existence values wolves have in a hunting district make it difficult to determine how a marginal increase in the wolf population in period *t+1* would effect the marginal support the agency gets from an increase in the elk population in period *t*+1. If these effects reduce hunter values received from a permit in period *t+1*, then $\frac{\partial^2 H_{t+1}}{\partial e_{jt+1}\partial w_{jt+1}}$ can be signed as negative. Similar impacts occur through recreationist support $\left(\frac{\partial^2 R_{t+1}}{\partial e_{jt+1}\partial w_{jt+1}}\right)$.

Determining the cross-district effects of wolves and elk are also important in determining a sign for each of the comparative statics. While, as previously discussed, an increase in the elk population in district *j* increases hunter support, it is likely that a marginal increase in the elk population in district *k* will reduce the marginal support gained from a marginal increase in the elk population in district *j*. Such a case would allow $\frac{\partial^2 H_{t+1}}{\partial e_{jt+1}\partial e_{kt+1}}$ to be signed as negative. Similar impacts can also be signed for recreationist value $\left(\frac{\partial^2 R_{t+1}}{\partial e_{jt+1}\partial e_{kt+1}}\right)$.

The cross effect of wolves in district *j* on the marginal support the agency gains from elk in district *k* depends on a number of factors. If wolves in district *j* positively (negatively) impact hunter support in district *k*, then it is likely that a marginal increase (decrease) in wolves in district *j* would decrease (increase) the hunter support gained from a marginal increase in the elk population in district *k*. However, if wolves in district

j negatively impact hunter support, the opposite case would be true. Similar impacts can also be signed for recreationists. $\frac{\partial^2 H_{t+1}}{\partial e_{kt+1}\partial w_{jt+1}}$ and $\frac{\partial^2 R_{t+1}}{\partial e_{kt+1}\partial w_{jt+1}}$ can be signed depending on the weight of these various impacts.

Both hunters and wolves are elk predators. The number of permits issued in this model signifies the number of hunters. A marginal increase in either of these predators in period *t* will reduce the elk population carried over to period *t+1*, thus $\frac{\partial e_{jt+1}}{\partial i_{jt}}$ and $\frac{\partial e_{jt+1}}{\partial w_{jt}}$ are both negative. The wolf population in period *t+1* is assumed here to be only as a function of the wolf population in period *t*. A marginal increase in the wolf population in period *t* will likely increase the wolf population at the margin in period *t+1*, so $\frac{\partial w_{jt+1}}{\partial w_{jt}}$ is positive.

Wolves in period *t* would likely reduce harvest rates by hunters in period *t*. Therefore, a marginal increase in the number of wolves would likely reduce the marginal impact of an additional permit issued on the elk population in period *t+1*, and $\frac{\partial^2 e_{jt+1}}{\partial i_{jt}\partial w_{jt}}$ can then be signed as negative.

From the discussion above, S_{12} and S_{21}, which are equal by the symmetry conditions of the Hessian matrix, can both be signed as negative. However, the sign of the terms contained in equations (3.3) and (3.4) are dependent upon the effects of wolves

on hunter value in the wolf-inhabited district $\left(\frac{\partial V_{1t}}{\partial w_{1t}}\right)$, district 1. If the sum of these values is negative, then A_2 is negative. The $\frac{\partial^2 H_{t+1}}{\partial e_{jt+1}\partial w_{jt+1}}$ and $\frac{\partial^2 R_{t+1}}{\partial e_{jt+1}\partial w_{jt+1}}$ terms are likely small in absolute value. Therefore, A_1 is also expected to be negative because the only positive line in the bracket of equation (3.7) contains these terms. Under these conditions, $\frac{\partial i^*_{1t}}{\partial w_{1t}}$ can be signed as negative, which indicates a marginal increase in wolves in district 1 would reduce the number of permits issued in district 1. Due to opposing values, no sign can be obtained for $\frac{\partial i^*_{2t}}{\partial w_{1t}}$. On the other hand, if the total effects of wolves on hunter values in district 1 are positive, no sign can be obtained for either comparative static.

CHAPTER 4

DATA

In this chapter a thorough description of the data will be undertaken to familiarize the reader with the available resources used to construct the variables included in the empirical models. Due to the variation of the data and variables between the cow permit, either-sex/bull-only permit, and the general license empirical models, this chapter will not contain an in-depth description of the variables contained in the empirical models. Variable descriptions and statistics will be included in each corresponding section of Chapter 5 and Appendix C, respectively.

Hunting and Harvest Report Data

Each year after the hunting season Montana Fish, Wildlife, and Parks (MFWP) surveys holders of general elk licenses and limited elk hunting permits. Using the data received from the surveys, MFWP estimates a number of hunting and harvest variables. The variables are listed by hunting district and subdivided by license type. There are three main types of elk hunting licenses in Montana; the general hunting license, a special permit license, and an A7 license. The distinction between an A7 license and a special permit license is that the A7 license holder may not participate in general license hunting, while a special permit holder is able to hunt using the general license or the special permit (MFWP, Elk Hunting and Harvest Reports, various years). However, hunters holding a general license and a special permit are only able to harvest an elk using one license/permit or the other. Thus, once one license/permit has been filled the hunter may

not harvest an additional elk using the other unfilled license/permit (MFWP, Elk Hunting and Harvest Reports, various years).

The hunting and harvest variables include; the number of permits issued, hunters, hunter days, total elk harvested, harvest composition (antlered or antlerless), percent success of harvest, average days to kill, and days per hunter (MFWP, Elk Hunting and Harvest Reports, various years). Generally these reports are released annually by MFWP each year for the prior year's hunting season data. However, MFWP has not released the elk hunting and harvest reports from the license years 1996 through 1998. Due to this lack of data the empirical estimation will use the annual hunting and harvest data from the license years 1999 through 2002.

Hunting Regulation Data

Each spring MFWP releases the elk hunting regulations for the upcoming hunting season. The hunting regulations communicate the district specific guidelines by which hunters must abide by to hunt within a Montana hunting district. The hunting regulations for each district include; hunting district boundaries, hunting season dates, weapons restrictions, and harvest restrictions for both general license hunting and special permit hunting (MFWP, Big Game Hunting Regulations, various years). In addition, the regulations notify hunters of the number of permits that will be issued in each district for the upcoming hunting season. The regulations also provide hunters with information on the previous year's drawing statistics. These drawing statistics show the number of permits issued the previous year, as well as the number of applicants for each permit, allowing hunters to estimate the odds of drawing a special permit. In some hunting

districts the number of permits that MFWP states will be issued (advertised quota) differs from the number of permits issued during the hunting season (actual quota) (MFWP, Big Game Hunting Regulations, various years).

Wolf Data

The wolf data used in the empirical estimations of this thesis were compiled from a number of different sources. Wolf data prior to 1996 was obtained from annual wolf reports released by the USFWS in conjunction with other various agencies. These annual reports include wolf pack locations and size for Northwest Montana wolf populations (USFWS 1994, Montana Interagency Wolf Working Group). In 1995 wolves were re-introduced into the Greater Yellowstone Area (GYA) by the USFWS. Wolf pack size and distribution in the GYA was reported in the Yellowstone Wolf Project Annual Report (Yellowstone Wolf Project Annual Report, various years). While data was available for pack size and distribution in the GYA for 1997 and 1998, no such data was available for the Northwest Montana wolf populations during these years. Wolf pack size and distributions in Northwest Montana for 1997 and 1998 were estimated using the reports available for these populations in 1996 and 1999 with consultation with Ed Bangs (October 2004), a wolf biologist with the USFWS.

The wolf data from 1999 to 2003 used in this thesis is from the Northern Rocky Mountain Wolf Recovery annual reports produced by the USFWS in conjunction with other various agencies. The data in these reports include the pack size and distribution of all wolf packs in the Northern Rocky Mountain Recovery Area (NRMRA), which

encompasses all of Montana (USFWS, Rocky Mountain Wolf Recovery Report, various years).

Wolf pack sizes and distributions were combined with the hunting district maps to determine which districts were inhabited by wolves each year. Distinctions were made between wolves whose distribution was contained within a single hunting district (single-district wolf packs), and those packs whose distribution included more than one hunting district (multiple-district wolf packs). The number of single-district wolves, number of multi-district wolves, and the number of years wolves have inhabited the district were recorded for each hunting district each year.

Weather Data

The weather data used in this thesis was obtained from the National Oceanic and Atmospheric Administration (NOAA). NOAA releases annual summaries of climatological data of all weather stations in the United States, including the monthly precipitation and average monthly temperatures for all Montana weather stations (NOAA, Climatological Data Annual Summary, various years). Each hunting district was designated a weather station based on the closest weather station to the district.

Land Data

MFWP offers an interactive hunt planner on the Internet. The hunt planner provides district-by-district regulations, topography, and land ownership maps (www.fwp.state.mt.us). These maps were used to estimate the percentage of private land

covering each hunting district. Hunting districts were classified into one of three discrete categories: 0 to 33 percent, 34 to 66 percent, or 67 to 100 percent private land.

The distance of a hunting district from a major Montana city is likely a factor impacting hunter demand. To record data that would capture this effect, the straight-line distance in miles was measured from a major Montana city to the border of a hunting district line using a map of Montana. While this data is extremely raw in form it does provide a basic measurement to capture the desired effect. The major cities used were; Billings, Bozeman, Butte, Helena, Missoula, Great Falls, and Kalispell.

Boone and Crockett Club Data

The Boone and Crockett Club (BCC) records information on antler scores of trophy game animals in North America. Data on the number of bull elk recorded in Montana for the years 1982 to 2002 were gathered from the BCC's online game records. This data contains the score, location of harvest, date of harvest, and ranking of all reported bulls killed in Montana with a score of over 360 points. The location of each harvested bull is listed as the county in Montana that the bull was harvested in. The number of BCC bulls was recorded for each county (BCC 2004). The number of BCC bulls for each hunting district was then designated based on the county in which the hunting district was located.

Non-Wolf Predator Data

Other large predators of concern for this thesis are black bear, grizzly bear, and mountain lions. Each year MFWP releases the Mountain Lion hunting regulations

informing lion hunters of the district specific regulations and district lion quotas. The lion quota for each elk district was recorded. However, the lion quotas across districts and within districts across time have very little variation, and thus are likely of limited use in the empirical section of this thesis.

Each year in the black bear hunting regulations released by MFWP, a map is provided describing the general distribution of grizzly bear populations in Montana (Montana 2004 Black Bear Hunting Regulations). However, no information on grizzly bear population densities is provided and is not readily available for the state of Montana. Due to this lack of data no information was recorded on grizzly bear distribution or population, and the effects of grizzly bear on elk hunting will be not be included in this thesis.

No estimates on black bear population and distribution are available for Montana. However, similar to other big-game species, MFWP releases annual hunting and harvest data on black bear (MFWP, Black Bear Hunting and Harvest Report 2002). From these reports the number of black bear harvested in each black bear hunting district was recorded. The lagged number of black bear harvested will be used as an estimate for the black bear populations within Montana hunting districts. Black bear hunting districts are generally larger than elk hunting districts, sometimes containing two or three elk districts. Both species' hunting areas do share similar district boundary lines. An elk hunting district's black bear harvest was estimated by dividing the black bear district's bear harvest by the number of elk districts it encompasses. This number was given to each of the elk districts within the border of the bear-hunting district.

CHAPTER 5

EMPIRICAL MODELS AND RESULTS

The empirical models developed in this thesis quantify the effects of wolves on hunter demand, the quality and quantity of elk hunting permits in Montana, as well as the quality of general license hunting in Montana. In developing these models a few considerations must be addressed.

In general, hunters are expected to gain more value from harvesting a bull elk than a cow elk. It is also likely that other hunt characteristics are valued differently for hunters who have the rights to kill a bull elk relative to hunters who have the rights to kill a cow elk. Also, the variables impacting elk populations are likely to impact bull elk differently than cow elk. Due to this likely diversity in the values hunters gain from these permits, as well as the biological differences between cow and bull elk, the models used in this thesis will be tested separately for (1) cow permits, and (2) either-sex and bull-only permits. Also, a separate model will be used to test the impacts of wolves on general license elk hunting in Montana.

Discussion with a wolf biologist, Ed Bangs, of the USFWS, suggested that wolves in different portions of Montana should be treated differently in the empirical models (October 2004). Three distinctions were made between wolf populations throughout the state of Montana due to differences in prey composition and habitat differences. First, Northwest Montana wolves are reported to primarily prey on deer. Therefore, all packs in Northwest Montana will be classified separately. Second, packs surrounding Yellowstone

National Park typically have a wider distribution than wolves in other portions of the state. Also, the dynamics of the elk population in the region around Yellowstone are thought to be different from elk populations in other portions of Montana. Therefore, wolves inhabiting hunting districts contained in Region 3 and Region 5 will be classified as Southwest Montana Wolves. Finally, wolves inhabiting other portions of the state are reported to primarily prey on elk and will be classified separately as Central Montana Wolves.

Estimating the outright quantity of hunting permits issued and the quality of these permits, as defined by hunter success rates, is even more difficult than estimating the level of each hunting district's elk population. Each hunting district's elk population is a complicated function of previous years' predation, weather variables, human effects, forest fire activity, food and water resources, other habitat information, and the district's size and hunting regulations. Due to the lack of adequate data needed to estimate the levels of the elk population, the models used in this paper will estimate the *change in* these elk permit quantity and quality variables rather than their levels. Using these change variables allows for a more simple set of models to be used in estimating the impacts of wolves on big-game hunting in Montana. The change variables were obtained by gathering data for each permit/license type for each district. These observations were then matched from year to year with the equivalent permit/license types for year *t* and year *t-1* and differenced to obtain the change in variables. In some cases there were various permit inconsistencies from year to year. There were many instances of permits changing from an either-sex permit one year into bull-only and cow-only permits the next, and

visa-versa. In such cases the bull-only and cow-only permits were combined into one either-sex classified permit and matched with the either-sex permit from the corresponding year. Other cases arose where permit regulations changed from year to year and no adequate data adaptations could be made. In these cases, the permit observations were dropped from the sample.

Wolves could affect the quality of elk permits and hunting values in two ways, and the magnitudes of each impact are highly dependent upon the management strategies undertaken by MFWP. Wolf predation and distributional effects on elk populations could reduce harvest rates by hunters. The ideal dependent variable to estimate the impact of wolves on hunter harvest rates is the change in the percent success of harvest. However, since this harvest rate variable is a proportion and, therefore, adjusted for district sizes and elk population differences, the problem arises of which explanatory variables to include in the model to estimate a change in a proportion. Therefore, the effects of wolves on harvest rates of hunters will be modeled using the change in hunter harvest as the dependent variable. The estimated wolf impacts on hunter harvest will be translated into changes in hunter success rates at the means for each wolf region. Given this impact on harvest rates, a model of hunter demand will be estimated to assess the marginal values hunters place on these changes in success rates.

Wolf predation is likely to negatively affect the number of elk hunting permits issued by MFWP. A model will be estimated to assess the change in the number of permits issued due to the actual or expected impacts of wolf predation on elk populations. Hunter demand models will then be estimated to assess the impacts of wolves on hunting.

These hunter demand models will estimate the marginal value hunters place on hunting in an area inhabited by wolves.

The empirical models were first estimated using Ordinary Least Squares (OLS). Since time series and cross section data was used in the change in hunter harvest and permits issued model estimations, there are two potential problems common with using OLS to estimate these models, auto-correlation and heteroskedasticity. While the test for auto-regressive errors was insignificant in each model, both the change in hunter harvest and change in permits issued models tested significantly for heteroskedasticity. Using OLS to estimate these models with heteroskedastic errors would produce biased standard errors and t-statistics. In some cases outliers in the data can cause black box tests for heteroskedasticity to show significance. Each model was checked for outliers in the data using graphical methods. Since a black box test was used to check for heteroskedastic errors, the regressions were rerun with the outliers removed from the data set. With the outliers removed each model again tested significantly for heteroskedastic errors, and the estimation results were qualitatively consistent with the models including the outliers. A White estimator was used to correct for the heteroskedasticity in the change in hunter harvest and change in permits issued models. To control for endogeniety in the change in hunter harvest and change in permits issued models, two-stage least squares was used, instrumenting for the endogenous variable. Also, given the lack of consistency in the number of observations for the dependent variables a systems estimator was not used.

The remainder of this chapter contains three sections: Change in Hunter Harvest Models, Change in the Number of Permits issued Models, and Hunter Demand Models.

First, each section will contain a general model and variable description. Second, the sections will include sub-sections for each permit/license type for which empirical estimations will be made. These sub-sections will include permit/license type specific model and variable descriptions, as well as the results of the empirical estimations for each model. These sections will contain only a general discussion of the model results. The estimated impacts of wolves on big-game hunting in the wolf-inhabited regions of Montana will be reported in Chapter 6. The variable summary statistics for each regression are shown in their respective tables in Appendix C.

Change in Harvest Rate Models

The dependent variable used to evaluate the wolf's impact on hunt quality is the change in hunter harvest. Estimating the impacts of wolves on this hunter harvest variable requires a model that accounts for various predation factors, management policies, and other environmental factors. The models used here will attempt to account for these factors using available data. As previously discussed, estimating the outright level of hunter harvest is complicated and requires data that cannot be reasonably obtained. However, estimating the change in hunter harvest from year to year simplifies the model to a useable form. The magnitude of the impacts the explanatory variable have on the change in hunter harvest will vary with the size of the elk population in each district. To control for this effect each explanatory variable will be interacted with the lagged number of elk harvested. Interacting each variable with this lagged harvest variable will adjust the impact of each variable on the change in hunter harvest proportionately.

The annual hunting and harvest data released by MFWP was used to construct change in hunter harvest variables for special permits and general license hunting. The definition of hunter success varies with the type of permit or license type. The overall hunter harvest is likely a good estimate of hunt quality obtained by cow and bull-only permit hunters. However, the best estimate for the hunt quality for either-sex permit hunters is the number of harvested bull elk. These variables will be used to estimate the hunt quality hunters obtained from participating in hunting with a specific permit/license type.

Estimating the change in hunter harvest requires the use of variables that affect the pre-season elk population and variables that capture the differences in hunting season conditions. Variables that impact pre-season elk populations include Winter, Spring and Summer weather measures, as well as predation. These variables impact elk population recruitment and mortality rates, as well as overall herd health. Weather variables considered include January through March precipitation and average temperature, as well as April through August precipitation. While winter snowfall is likely to positively effect elk populations to a certain level, extreme snowfall is likely to negatively impact elk populations. A January through March precipitation squared variable will also be considered in the models to control for this effect.

A number of factors likely affect the impact wolves have on the elk population in a hunting district. The wolf predation variables included in the model will capture how the presence of wolves in a district, the level of wolves in a district, the intensity at which wolves move into a district, and the longevity of the wolf's presence within a district

affect changes in elk harvest and permits issued. Each wolf variable used in the models will be modeled to capture one or more of these effects.

It is likely that the impacts of wolves on elk in the first few years of their existence in a hunting district is likely to differ from impacts of wolves in the longer-run. Wolves moving into a hunting district cause elk behavior and distribution to change (Creel and Winnie 2004). Since wolf population numbers generally experience the greatest change within the first three years of wolf inhabitance (USFWS Northern Rocky Mountain Wolf Recovery Annual Reports, various years), it is likely that the elk distributional effects of wolves impact changes in harvest rates and permits issued greatest within these first three years. Hunters generally harvest adult elk. Therefore, elk calves are not "realized" into the harvestable population until two to three years of age. Therefore, wolf predation on elk calves is not likely to affect hunter harvest rates within the first few years of wolf existence. One variable that captures the initial elk distributional effects of the wolf's presence in a hunting district, as well as the different impact wolf predation is likely to have on hunter harvest within the first few years of wolf existence, is a dummy variable signifying the first three years of inhabitance by a wolf pack in a hunting district. This initial wolf pack dummy variable was given a value of one if wolves had inhabited the district for three years or less and a value of zero if wolves had never inhabited the district, or if wolves had inhabited the district for over three years. In some cases a wolf pack's distribution overlapped two hunting districts. It is likely that these multiple-district wolf packs have a significantly different elk distributional impact than do the single district wolf packs. Therefore, two separate

dummy variables were created; one for multiple-district packs and another for single-district packs. This initial wolf pack inhabitance variable is modeled to capture these wolf effects on the change in percent success of harvest.

The level of the increase of wolves into a hunting district is likely to affect their impact on elk distribution and predation effects on elk. A variable constructed to capture this effect is the difference in the wolf population from the previous five-year average wolf population. To simplify the model, single-district wolves and multiple-district wolves will be included together in this variable. To control for the differences in wolf impacts on elk between single-district wolves and multiple-district wolves, the multiple-district wolves were each given a value of 0.5 while the single-district wolves were each given a value of 1.

The number of wolves inhabiting a hunting district and the length of time wolves have inhabited a district are also modeled to impact the change in hunter harvest. One variable that will be used to capture this numerical effect of wolves is the five-year average wolf population. Single district wolves were each given a value of one while the multiple-district wolves were each given a value of 0.5 in this five-year average.

To account for the potential predation of black bear on elk, another predation variable included in these models is the lagged black bear harvest estimated for each district.

Weather and predation also effect elk distribution during the hunting season. Weather changes and differences in predation can distribute elk differently within and across hunting districts. Variables that capture differences in hunting season conditions

include; differences in hunting season weather, distributional effects due to new predation by wolves, changes in the number of hunters, and changes in hunting regulations. Controlling for these elk distribution factors will allow a useful model to be constructed to estimate the impact of wolves on the elk harvest by hunters. Weather conditions likely affect when hunters choose to hunt during the season and thus when elk are harvested. Therefore, the weather variables included in the model also capture the effects that weather has on when hunters choose to hunt and how this affects when hunter harvest occurs.

The number of harvested elk is also dependent upon the number of hunters each year. The number of hunters can vary from year to year due to changes in permit numbers, weather conditions, or hunter demand. In special permit hunting MFWP adjusts permit numbers based on a number of factors that affect elk populations, including weather and predation. A model will be used to estimate the impacts of wolves on the number of permits issued. Therefore, the change in hunter harvest models must control for this adjustment in the number of permits issued, used as a percentage in the regression, so the estimated wolf impacts do not double count these effects. An endogeniety problem exists with this variable in the model because setting permit numbers is an agency decision that is a function of a number of variables, many of which are included in this model. To correct for this endogeniety two-stage least squares was used and the percent change in permits issued variable was instrumented for using the other explanatory variables in the model as well as regional dummy variables.

Other variables that impact the change in hunter harvest are changes in regulation variables. MFWP may choose to limit hunter harvest by implementing additional harvest restrictions or reducing the number of season days. However, an endogeniety problem exists when including these variables in the model. Changing regulations is an agency decision that is difficult to instrument for, so these change in regulation variables will not be included in the empirical estimations.

The sample was split for all dependent variables into (1) cow permits and (2) either-sex and bull-only permits. The results for each of the sex-type models are shown in their respective sections.

Cow Permit Regression Results

The dependent variable used to estimate the impact of wolves on the hunt quality of cow elk permits is the total change in hunter harvest from year to year. The summary statistics for the variables used in the cow permit change in harvest regression model are shown in table C.1 of Appendix C.

The results for the cow permit change in hunter harvest regression model are shown below in table 5.1.

Table 5.1. Change in special permit hunter harvest regression results.
Dependent Variable = Change in Hunter Harvest.

Variable Name	Cow-Only	Either-Sex/ Bull-Only (1)	Either-Sex/ Bull-Only (2)
Northwest Montana Wolf Variables			
Initial Single District Wolf Pack Inhabitance Dummy	0.050 (0.466)	Omitted	Omitted
Initial Multiple-district Wolf Pack Inhabitance Dummy	-0.097 (0.600)	Omitted	Omitted
Five Year Average Wolf Numbers	-0.019 (0.036)	Omitted	Omitted

Table 5.1. Change in special permit hunter harvest regression results (continued). Dependent Variable = Change in Hunter Harvest.

Variable Name	Cow-Only	Either-Sex/ Bull-Only (1)	Either-Sex/ Bull-Only (2)
Northwest Montana Wolf Variables			
Wolf Number Difference from 5 Year Average	-0.069 (0.050)	Omitted	Omitted
Central Montana Wolf Variables			
Initial Single District Wolf Pack Inhabitance Dummy	-0.187 (0.150)	Omitted	Omitted
Initial Multiple-district Wolf Pack Inhabitance Dummy	0.117 (0.084)	Omitted	Omitted
Five Year Average Wolf Numbers	-0.008 (0.016)	Omitted	Omitted
Wolf Number Difference from 5 Year Average	-0.044** (0.022)	Omitted	Omitted
Southwest Montana Wolf Variables			
Initial Single District Wolf Pack Inhabitance Dummy	0.012 (0.124)	0.318*** (0.100)	0.172*** (0.048)
Initial Multiple-district Wolf Pack Inhabitance Dummy	0.127 (0.342)	-0.079 (0.170)	-0.127** (0.057)
Five Year Average Wolf Population	-0.145*** (0.033)	-0.085** (0.035)	-0.035* (0.018)
Wolf Number Difference from 5 Year Average	0.037*** (0.007)	0.037*** (0.011)	0.015*** (0.005)
Other Model Variables			
Percent Change in the Number of Permits Issued	0.007* (0.004)	0.006 (0.015)	0.008 (0.008)
Black Bear Harvest (lagged)	0.001 (0.003)	-0.002 (0.013)	-0.006 (0.005)
January-March Precipitation	-0.028 (0.048)	-0.017 (0.062)	-0.030 (0.021)
January-March Precipitation Squared	0.003 (0.006)	0.000 (0.006)	0.004* (0.002)
April-August Precipitation	-0.022 (0.014)	-0.007 (0.021)	0.003 (0.009)
January-March Average Temperature	0.002 (0.003)	0.003 (0.005)	0.000 (0.002)
Change in October Precipitation	0.050* (0.029)	0.052 (0.041)	-0.017 (0.020)
Change in November Precipitation	-0.065 (0.046)	0.147* (0.075)	0.050* (0.029)
Change in December Precipitation*Late season Dummy	0.083 (0.098)	0.095 (0.165)	0.137 (0.090)
Change in September Temperature	0.020 (0.017)	-0.014 (0.018)	0.004 (0.009)

Table 5.1. Change in special permit hunter harvest regression results (continued). Dependent Variable = Change in Hunter Harvest.

Variable Name	Cow-Only	Either-Sex/ Bull-Only (1)	Either-Sex/ Bull-Only (2)
Change in October Temperature	-0.054*** (0.020)	-0.016 (0.018)	-0.014 (0.010)
Change in November Temperature	-0.015*** (0.003)	-0.018*** (0.003)	-0.005*** (0.002)
Change in December Temperature*Late season Dummy	-0.015 (0.019)	-0.006 (0.049)	0.020 (0.020)
Adjusted R-Squared	0.720	.737	.224
Standard Error of Regression	16.945	24.707	10.024
Observations	427	242	242

Notes: All variables are interacted with the lagged number of harvested elk. Standard errors are shown in parentheses under the coefficients. * Signifies significance at 10 percent confidence level. ** Signifies significance at 5 percent confidence level. *** Signifies significance at 1 percent confidence level.

The Northwest Montana wolf variables do not significantly impact the change in hunter harvest jointly. These results suggest that if wolves are impacting cow elk populations in these regions, that MFWP is adjusting permit numbers such that hunter harvest rates are not significantly affected.

The set of Central Montana Wolf Variables and the set of Southwest Montana Wolf Variables are each jointly significant at the 1 percent confidence level. These results suggest that, although MFWP maybe managing cow elk permit numbers, wolves are significantly impacting hunter harvest rates for cow permits in Central Montana and Southwest Montana wolf districts. The impacts on cow elk harvested of these wolf variables at their respective means are positive or negative depending on which wolf districts are considered. These effects will be explained further in Chapter 6.

Other variables significantly impacting harvest at the 5 percent significance level during the time period considered are the change in October and November temperature

variables. These variables represent the difference in hunting season weather, which affects elk distribution during the hunting season. These results suggest that for each degree Fahrenheit the average temperature for October or November are reduced relative to the previous year's average temperature hunter harvest is increased by about 2 elk in October and .6 elk in November at the mean.

Either-sex and Bull-only Permit Regression Results

Two measures will be used to estimate the change in hunt quality due to the impacts of wolves on either-sex and bull-only special permits. While the success rates of harvesting a bull elk are the best measure of hunt quality of either-sex and bull-only permits, hunters also gain value from harvesting cow elk using their either-sex hunting permit. First, a model using the change in total elk harvested will be used to estimate the overall change in hunt quality of these permits. This total change in harvest model is found under Either-Sex/Bull-Only (1) in table 5.1. Second, a model using the change in the number of bull elk harvested will be estimated. This change in the number of bulls harvested model is found under Either-Sex/Bull-Only (2) in table 5.1. Both models provide useful information of how these permits are being affected, and more specifically how wolves are affecting the harvest rates of bull elk and cow elk for these permits.

The either-sex and bull-only permits are limited to hunting regions three, four, five, six, and seven. The wolf-inhabited hunting districts included in these either-sex/bull-only permit observations are limited to districts inhabited by Southwest Montana Wolf packs. Therefore, the only set of regional wolf variables included in the either-sex/bull-only permit model is limited to the Southwest Montana Wolf Variables.

The summary statistics for the variables used in the either-sex/bull-only change in harvest models are shown in table C.2 in Appendix C.

Wolf variables in both either-sex/bull-only models (Model 1 and Model 2) are jointly significant at the 1 percent confidence level (table 5.1). The joint impact of these wolf variables at their respective means is negative or positive depending on which wolf districts are considered. These effects will be explained further in Chapter 6. These results suggest that although MFWP maybe managing elk permit numbers, wolves are significantly impacting hunter harvest rates for either-sex/bull-only permits in hunting districts inhabited by Southwest Montana wolf packs.

Other variables significant at the 5 percent confidence level in these models include the change in November temperature for both Either-sex/Bull-Only models. The results for model 1 suggest a one degree Fahrenheit drop in temperature from the previous year's average November temperature increases the total number of elk harvested by .7. The results for model 2 suggest a one degree Fahrenheit drop in temperature from the previous year's average November temperature increases the total number of bull elk harvested by .06. Comparing these results suggests that November temperature affects hunter harvest of cow elk greater than hunter harvest of bull elk.

General License Regression Results

The general license elk-hunting season in Montana is managed by MFWP through harvest regulations. These harvest regulations include; setting season dates, sex restrictions, weapons restrictions, and antler restrictions. However, unlike the special permit hunts, hunters holding a general hunting license are free to hunt in any hunting

district open to general license hunting. Therefore, if wolves are negatively impacting elk populations, hunters previously hunting in these wolf-inhabited districts will likely transfer to non-wolf-inhabited districts so that the marginal value of hunting on any given day is equal across all hunting districts where general license hunting is allowed. These hunters transferring from district to district is much like the equilibrium in the special permit market where lottery entrants transfer to other lotteries such that the marginal value of entering into any given lottery for a special permit is equal.

A model will be used to estimate the change in each district's general license hunter harvest from year to year. The variables included in the model are similar to the models used to estimate the special permit change in hunter harvest. All previously discussed regional wolf variables will be included as an explanatory variable in the model. To control for the impact of changes in the number of hunters on the change in hunter harvest, a percentage change in the number of hunters variable will be included in the model. An endogeniety problem exists with this percentage change in the number of hunters variable because it could be written as a function of the other variables in the model. Therefore, two-stage least-squares will be used, and the other explanatory variables in the model, as well as regional dummy variables, will be used to instrument for this percentage change in the number of hunters variable.

For the estimation of this percentage change in the number of hunters, the wolf variables in the model will estimate the impacts of wolves on hunter harvest after hunters have adjusted their hunting areas. For example, if wolves are negatively impacting elk populations in one district, then hunters will likely leave that wolf-inhabited district and

either hunt in another district, or quit hunting entirely. The hunters remaining in the wolf-inhabited district then attain higher harvest rates than would occur without such hunting area adjustment. If hunters are adjusting optimally in this way in these wolf-inhabited districts, then the model would likely estimate no excess impacts of wolves on general license hunters within a given district. However, if hunters are not fully adjusting to wolf predation, then the model will estimate negative impacts of wolves on hunter harvest within that district. Therefore non-significant wolf variables are consistent with general license hunters adjusting to wolf predation in wolf-inhabited districts.

The variable summary statistics for the general license change in hunter harvest model are shown in table C.3 of Appendix C.

As with the special permit models, each explanatory variable in the general license change in hunter harvest model is interacted with the lagged hunter harvest. The model results are reported in table 5.2.

Table 5.2. Change in general license hunter harvest regression results.
Dependent Variable = Change in Hunter Harvest.

Variable Name	**General License Change in Hunter Harvest Model Results**
Northwest Montana Wolf Variables	
Initial Single District Wolf Pack Inhabitance Dummy	0.460** (0.213)
Initial Multiple-district Wolf Pack Inhabitance Dummy	-0.134 (0.189)
Five Year Average Wolf Numbers	0.009 (0.022)
Wolf Number Difference from 5 Year Average	-0.035 (0.024)
Central Montana Wolf Variables	
Initial Single District Wolf Pack Inhabitance Dummy	0.052 (0.191)
Initial Multiple-district Wolf Pack Inhabitance Dummy	-0.144* (0.087)
Five Year Average Wolf Numbers	-0.010 (0.010)

Table 5.2. Change in general license hunter harvest regression results (continued). Dependent Variable = Change in Hunter Harvest.

Variable Name	General License Change in Hunter Harvest Model Results
Central Montana Wolf Variables	
Wolf Number Difference from 5 Year Average	-0.060*** (0.021)
Southwest Montana Wolf Variables	
Initial Single District Wolf Pack Inhabitance Dummy	0.346* (0.193)
Initial Multiple-district Wolf Pack Inhabitance Dummy	-0.034 (0.139)
Five Year Average Wolf Numbers	0.027 (0.029)
Wolf Number Difference from 5 Year Average	-0.006 (0.020)
Other Model Variables	
Percent Change in the Number of Hunters	0.018*** (0.005)
Black Bear Harvest (lagged)	-0.001 (0.002)
January-March Precipitation	0.039 (0.031)
January-March Precipitation Squared	-0.004* (0.003)
April-August Precipitation	-0.015 (0.011)
January-March Average Temperature	0.004 (0.002)
Change in September Precipitation	-0.057 (0.037)
Change in October Precipitation	0.046* (0.024)
Change in November Precipitation	-0.124*** (0.036)
Change in September Temperature	0.008 (0.014)
Change in October Temperature	-0.029** (0.014)
Change in November Temperature	-0.013*** (0.003)
Adjusted R-Squared	0.664
Standard Error of Regression	28.528
Observations	405

Notes: All variables are interacted with the lagged number of harvested elk. Standard errors are shown in parentheses under the coefficients. * Signifies significance at 10 percent confidence level. ** Signifies significance at 5 percent confidence level. *** Signifies significance at 1 percent confidence level.

Joint significance tests on the regional wolf variables show that only the Central Montana Wolf variables, which are jointly significant at the 1 percent level, are significant at least at the 5 percent confidence level. The joint effect of these wolf variables is negative. The insignificance of the Northwest Montana Wolf variables and the Southwest Montana wolf variables is consistent with hunters adjusting to wolf predation such that additional impacts on hunter harvest rates are not realized.

Other variables significant at the 5 percent level include many of the weather variables and the percent change in the number of hunters variable. The change in November precipitation, October temperature, and November temperature all have negative coefficients, which indicates a reduction in these variables from one year to the next leads to an increase in hunter harvest. The change in October precipitation has a positive coefficient, which indicates a reduction in October precipitation from one year to the next reduces hunter harvest. The percent change in the number of hunters is significant at the 1 percent confidence level. The positive coefficient suggests that as the number of hunters increases, the number of elk harvested increases as well.

Change in the Number of Permits Issued Models

A variable that measures the quantity of hunting available to hunters is the number of special elk permits issued. The change in these permits will be modeled by including many biological factors that likely impact elk populations. The decision by MFWP to set permit numbers at any given level is modeled as a function of a number of variables pertaining to various constituent groups, as well as biological factors impacting

elk populations. In addition, MFWP is also able to regulate harvest rates by hunters while maintaining permit numbers by placing additional hunting regulations upon permit/license holders. Also, hunter harvest and the annual elk counts by MFWP both fluctuate from year to year due to weather factors that affect elk distribution. These variations might affect MFWP's decision to change permit numbers each year based on harvest rates or count data. Instead, MFWP may adjust permit numbers in multi-year increments once sufficient evidence is obtained that elk populations have changed enough to warrant a change in the number of permits issued. All of these factors contribute to the complications of estimating the agency decision of setting permit numbers.

A modeling problem exists when comparing a change in the number of permits between two districts with drastically different elk populations. For example, a drought of equal magnitude in two hunting districts is likely to proportionally impact the elk population of both districts. However, permit numbers in a district with a larger elk population will likely be impacted more than will permit numbers in a district with a lower elk population.

One solution to this potential estimator problem is to run the model using the percent change in permit numbers as the dependent variable. Such a percent change approach gives rise to another problem in hunting districts with drastically different elk populations. An observation of a 10 percent decrease in permit numbers will be treated equally across districts, for example one district with 10 permits and one with 2000 permits issued. In this case a 1-permit drop in one district will be treated equally as a 200-

permit drop in the other district. Therefore, the change in the number of elk permits issued will be estimated. The explanatory variables in the regression will be interacted with the lagged number of permits issued, an endogenous variable that will be instrumented for. Interacting the variables with the lagged number of permits issued will adjust the effects of each variable by a magnitude in proportion to the elk population.

MFWP sets permit numbers in the spring prior to the fall hunting season, so the variables that will be included in the models will reflect the available information MFWP has prior to setting permit numbers. MFWP is modeled to set permit numbers based on an expected sustainable harvest level. Therefore, all variables that will be included in this model are those that are exogenous in MFWP's management decisions, such as weather variables and predation. The model will then produce estimates of how MFWP adjusts issued permits, based upon the estimated impacts of winter weather and predation, as well as the expected future impacts of predation upon elk populations.

The wolf variables in this change in permits issued model are the same wolf variables used in the corresponding change in hunter harvest models previously reported. The weather variables used in the model are the winter weather variables used in the previous models. Another variable included in the model is the lagged black bear harvest for each district. This variable will capture how MFWP adjusts permit numbers to potential black bear predation on elk populations.

Controlling for other regulatory decisions MFWP has to influence hunter harvest would be useful for this change in permits issued model. The decision to change hunting regulations is an agency decision, which is difficult to predict and gives rise to an errors

in variables problem. As a result, the change in regulation variables will not be controlled for in these change in permits issued models.

The summary statistics for the variables used in the change in permits issued regression model for cow permits and the either-sex/bull-only permits are shown in tables C.1 and C.2, respectively, of Appendix C. The empirical results for the cow and either-sex/bull-only change in permits issued models are reported in table 5.3.

Table 5.3. Change in the number of permits issued regression results.
Dependent Variable: Change in the Number of Permits Issued.

Variable Name	Cow-Only Model	Either-Sex/Bull-Only Model
Northwest Montana Wolf Variables		
Initial Single District Wolf Pack Inhabitance Dummy	0.361 (0.332)	Omitted
Initial Multiple-district Wolf Pack Inhabitance Dummy	0.729 (0.477)	Omitted
Five Year Average Wolf Numbers	-0.006 (0.019)	Omitted
Wolf Number Difference from 5 Year Average	0.025 (0.023)	Omitted
Central Montana Wolf Variables		
Initial Single District Wolf Pack Inhabitance Dummy	0.053 (0.142)	Omitted
Initial Multiple-district Wolf Pack Inhabitance Dummy	0.085 (0.185)	Omitted
Five Year Average Wolf Numbers	0.007* (0.004)	Omitted
Wolf Number Difference from 5 Year Average	0.003 (0.012)	Omitted
Southwest Montana Wolf Variables		
Initial Single District Wolf Pack Inhabitance Dummy	-0.088** (0.039)	0.002 (0.017)
Initial Multiple-district Wolf Pack Inhabitance Dummy	-0.361** (0.149)	-0.015 (0.014)
Five Year Average Wolf Numbers	-0.026** (0.011)	0.002 (0.003)
Wolf Number Difference from 5 Year Average	0.006* (0.003)	-0.010 (0.009)
Other Model Variables		
Lagged Number of Permits Issued	-0.127** (0.058)	-0.011 (0.027)
Black Bear Harvest (lagged)	-0.001 (0.002)	0.001 (0.003)

Table 5.3. Change in the number of permits issued regression results (continued). Dependent Variable: Change in the Number of Permits Issued.

Variable Name	Cow-Only Model	Either-Sex/Bull-Only Model
January-March Precipitation	0.099*** (0.037)	0.008 (0.011)
January-March Precipitation Squared	-0.010** (0.004)	-0.001 (0.001)
Adjusted R-Squared	0.289	-0.018
Standard Error of Regression	42.896	20.762
Observations	427	242

Notes: All variables are interacted with the lagged number of permits issued. Standard errors are shown in parentheses under the coefficients. * Signifies significance at 10 percent confidence level. ** Signifies significance at 5 percent confidence level. *** Signifies significance at 1 percent confidence level.

Cow Permit Regression Results

The change in the number of cow permits issued model results are shown in column two of table 5.3. The Northwest Montana wolf variables and the Southwest Montana Wolf Variables were both jointly significant at the 1 percent confidence level. The joint effect of the Northwest Montana Wolf Variables at their respective means is positive or negative depending on which wolf district is considered. The joint effect of the Southwest Montana Wolf Variables at their respective means is negative.

The lagged black bear harvest variable is significant at the 5 percent confidence level. The negative coefficient on this variable indicates an increase in the lagged black bear harvest leads to a reduction in the number of elk hunting permits issued. The January through March precipitation and precipitation-squared variables are both significant at the 5 percent confidence level. These variables together indicate that winter snowfall up to a point leads MFWP to increase permit numbers. However, this winter snowfall variable exhibits a diminishing positive marginal impact until it begins to negatively impact

permit numbers. The January through March average monthly temperature variable was not included in the cow permit model due to correlation of greater than .9 with the lagged number of permits issued variable.

Either-Sex/Bull-Only Permit Regression Results

The change in the number of either-sex/bull-only permits issued model results are shown in column three of table 5.3. There were no significant impacts of the variables included in the model. The wolf variables included in the model are also insignificant in the joint significance test at the five percent confidence level. The January through March average temperature variable was not included in the regression due to correlation of over .9 with the lagged number of permits issued variable.

Hunter Demand Models

Hunter demand is a key dependent variable for estimating the impacts of wolves on special permit elk hunting in Montana. The hunter demand models estimate the marginal value of hunting in a wolf-inhabited district. As previously discussed, the equilibrium condition in the “market” for these hunting permits is that the marginal value of entering into any given lottery is equal. The drawing odds attained by applicants for Montana’s limited elk permits measures demand for these permits. However, using the drawing odds as a dependent variable makes the interpretation of the coefficient estimates of the models difficult. The number of first choice applicants per permit issued will be used in the econometric models in this section to measure hunter demand. Using the number of first choice applicants per permit issued as a dependent variable will allow an

easy interpretation of the coefficients, as well as provide a useful model to estimate both impacts of wolves on hunter demand and game agency revenues. The explanatory variables that will be used to estimate the number of first choice applicants per permit issued impact the value permit winners receive and thus hunter demand for a permit.

The number of permits issued by MFWP during the hunting season sometimes differs from the permit quota MFWP states prior to hunters entering in the lottery for a permit (advertised quota). Hunters make their decision to enter a permit lottery based upon this advertised quota. Therefore, the number of first choice applicants per permit is calculated by dividing the number of first choice applicants by the advertised number of issued permits.

As previously discussed, a number of variables impact the value a hunter receives from a hunting permit, and thus the number of applicants for the permit. First, the hunting district, or districts, a permit allows a hunter to hunt in affects permit value. The accessibility and availability of public land for hunters to hunt on is likely a large factor impacting hunter demand for a permit. To capture the effects of these variables on hunter value, the percentage of private land encompassing a hunting district was included in the model. Two variables that are included in the model to capture the affect of land ownership on hunter value are an indicator variable for 33 percent to 65 percent private land variable and an indicator variable for 66 to 100 percent private land variable. Additionally a variable measuring the direct distance (in miles) from a major Montana city will be used to control for travel costs and other location factors that impact hunter values.

The hunting and harvest data released by MFWP each year (generally) provides hunters with information on the likely success rates for a special permit. Specifically, two variables, the percent success of harvest, and the average days to kill (ADTK) indicate to potential lottery entrants the success rates hunters have obtained in the past and thus the success rate they can expect to obtain from the permit. ADTK is an estimate of the average number of days a hunter hunts using the special permit before harvesting an elk. A few problems are associated with using ADTK in the model. First, hunters may choose to pass up many elk before choosing to harvest an animal, thus spending longer time in the woods and increasing the ADTK. Also, it is likely that the ADTK variable is much more vulnerable to random impacts such as changes in hunting season weather. Due to these factors the success rate variable used in the model to capture the effects of hunt quality on hunter demand is the percent success of harvest experienced by permit holding hunters, lagged. As previously discussed, a better indicator of hunt quality for either-sex hunters is the percent success of harvesting a bull elk. In the either-sex/bull-only models the percent success of harvesting a bull elk will be included in the models to measure expected hunt quality.

The regulations accompanying a permit also affect hunter demand. Variables indicating the relevant permit regulations will be included in the model. These variables differ between cow permits and either-sex/bull-only permits, and include harvest restrictions such as antler size requirements, late or early season hunt indicators, and weapon restrictions. The hunting regulation variables used in the models will also vary

from year to year due to new regulations instituted on hunting permits or regulations on hunting discontinued by MFWP.

The antler quality of the bulls within a hunting district is thought to impact hunter demand for either-sex and bull-only permits. One indicator of the antler quality experienced by hunters in an area is the number of Boone and Crockett Club bulls that have been harvested in the district. While the Boone and Crockett Club does not specify which hunting district the bulls were harvested in, it does list the county the bull was harvested in. Thus, the number of Boone and Crockett Club bulls killed in a county from 1982 to 2002 will be used as a variable to indicate the antler quality of harvested bulls in an area.

As previously noted, wolves could directly impact hunter demand for a permit in many ways. The wolf's existence value could positively or negatively impact hunter values. These values could also change over time once wolves have inhabited an area for many years. Also, depending upon the management strategy undertaken by MFWP, hunters may adjust expectations of success rates, thus impacting hunter demand. Wolf variables will be included in the models to indicate the intensity and longevity of the wolf's presence within a hunting district.

As previously discussed, hunters likely value cow permits differently from either-sex and bull-only permits. Also, the marginal value hunters gain from various permit characteristics is likely different for cow versus either-sex/bull-only permits. The cow permit regressions will be run separately from the either-sex/bull-only permit hunter demand regressions. Additional empirical concerns arise between differences in hunter

demand from 2000 to 2002. It is possible that hunters' views on wolves may change over the time period considered. Regressions combining these years together showed significant differences in hunter demand for permit characteristics from year to year. Due to these potential changes in hunter demand from year to year, the hunter demand regressions will be run separately for 2000, 2001, and 2002 for either-sex/bull-only permits and cow permits.

Cow Permit Regression Results

Dummy variables were included in the cow permit model to capture the effects of regulations on hunter demand. These variables include an early season dummy variable, an A7 license dummy variable, and a multiple-district dummy variable. Cow permits allowing hunters to hunt before October 15 were designated early season hunts. A value of one was given to any permit allowing hunters to hunt during the early season, while a value of zero was given otherwise. Late season hunts also exist for cow permits. A late season permit was defined as a permit allowing a hunter to hunt after December 15. A late season hunt dummy variable was given a value of one to any permit allowing permit holders to hunt during this late season, while a value of zero was given otherwise. For the A7 dummy, a cow permit designated as an A7 license was given a value of one, while all others were given a value of zero. Some cow permits allow hunters to hunt in multiple hunting districts. These multiple district permits were given a value of one, while all others restricting hunters to one district were given a value of zero for this dummy variable.

The summary statistics of the variables included in the 2000, 2001, and 2002 cow permit hunter demand models are shown in tables C.4, C.5, and C.6 respectively, in Appendix C. The cow permit hunter demand empirical results are shown in table 5.4.

5.4. Cow permit hunter demand model regression results.
Dependent Variable = Number of First Choice Applicants Per Permit Issued.

Variable	Year 2000	Year 2001	Year 2002
Constant	1.702***	1.222***	0.933***
	(0.510)	(0.364)	(0.285)
Early Season Dummy	-0.076	-0.135	0.108
	(1.288)	(0.592)	(0.406)
Late Season Dummy	-0.586	0.120	0.079
	(0.991)	(0.514)	(0.371)
A7 License Dummy	-1.449**	-1.058***	-0.692**
	(0.620)	(0.349)	(0.284)
Multi-District Dummy	0.855	0.952**	0.590
	(0.902)	(0.479)	(0.393)
Distance from Major Population Center	-0.036	0.015	-0.046
	(0.195)	(0.129)	(0.124)
33 to 65 Percent Private Land	-0.968*	-0.408	-0.419
	(0.567)	(0.332)	(0.298)
66 to 100 Percent Private Land	-1.053**	-0.971***	-0.773***
	(0.504)	(0.311)	(0.274)
Percent Success of Harvest (lagged)	0.048***	0.024***	0.036***
	(0.013)	(0.008)	(0.007)
Northwest Montana Wolf Variables			
Initial Single District Wolf Pack Inhabitance Dummy	No Observations	-1.230 (2.146)	-10.978 (11.135)
Initial Multiple-district Wolf Pack Inhabitance Dummy	No Observations	No Observations	3.610 (4.196)
Difference in Wolf Population from 5 year Average	0.356 (0.297)	1.017* (0.539)	1.454 (1.388)
5 Year Average Wolf Population	-0.215 (0.435)	0.953*** (0.222)	1.339 (0.948)
Central Montana Wolf Variables			
Initial Single District Wolf Pack Inhabitance Dummy	No Observations	No Observations	1.012 (0.719)
Initial Multiple-district Wolf Pack Inhabitance Dummy	No Observations	1.013 (1.091)	0.471 (1.465)
Difference in Wolf Population from 5 year Average	-1.506 (10.001)	0.031 (0.343)	-0.156 (0.186)
5 Year Average Wolf Population	-0.070 (0.192)	-0.015 (0.115)	0.049 (0.075)

5.4. Cow permit hunter demand model regression results (continued).
Dependent Variable = Number of First Choice Applicants Per Permit Issued.

Variable	Year 2000	Year 2001	Year 2002
Southwest Montana Wolf Variables			
Initial Single District Wolf Pack Inhabitance Dummy	No Observations	-1.759 (1.522)	-1.599 (1.297)
Initial Multiple-district Wolf Pack Inhabitance Dummy	-0.690 (1.572)	No Observations	No Observations
Difference in Wolf Population from 5 year Average	-0.102 (0.366)	0.074 (0.187)	0.044 (0.129)
5 Year Average Wolf Population	-0.067 (1.118)	-0.685 (0.941)	-0.282 (0.223)
Adjusted R-Squared	0.098	0.259	0.291
Standard Error of Regression	2.368	1.414	1.215
Observations	137	136	142

Notes: Standard errors are shown in parentheses under the coefficients. * Signifies significance at 10 percent confidence level. ** Signifies significance at 5 percent confidence level. *** Signifies significance at 1 percent confidence level.

The set of Northwest Montana wolf variables were jointly significant at the 1 percent confidence level in the 2001 model only. Since these Northwest Montana wolf variables were not jointly significant in both the 2000 and 2002 hunter demand models, it is likely that the wolf variables in the 2001 model are capturing an effect not controlled for in this model. The set of Central Montana and the set of Southwest Montana wolf variables were not jointly significant at the 5 percent level in any of the cow permit hunter demand models.

The A7 license and the 66 to 100 percent private land dummy variables were both negative and significant at the 5 percent confidence level in each hunter demand model. The lagged percent success of harvest variable and the constant were both positive and significant at the 1 percent level each year. The constant was positive and significant at the 5 percent level across each year.

Either-Sex and Bull-Only Permit Regression Results

Many regulations may accompany either-sex and bull-only permits. Some permits are specially designated as youth hunts. A dummy variable was created to control for this variable's impact on hunter demand, with a value of one given to designated youth hunt permits and a value of zero otherwise. Permits also differ in when they allow a hunter to hunt during the hunting season. Three distinctions were made between hunting permits that allow hunters to hunt during different time periods. Permits allowing hunters to hunt prior to October 15 were designated early season hunts. A dummy variable was created to capture the potential effect of this early season hunt on hunter value. Observations were given a value of one under this early season dummy if hunters were allowed to hunt during this early time period, zero otherwise. Similar distinctions were made for late season permits that allowed hunters to hunt after December 15. These late season hunts were given a value of one under the late season dummy, zero otherwise.

While either-sex permits allow hunters to harvest either a bull or a cow elk, bull-only permits restrict hunters to harvesting only bull elk. Therefore, potential differences in hunter demand may exist between either-sex permits and bull-only permits. To capture the potential difference in hunter demand between either-sex and bull-only permits, a bull-only dummy variable was included in the model to capture this effect. The bull-only dummy was given a value of one for bull-only permits, a value of zero otherwise. Some permits only allow either-sex hunting during a portion of the hunting season, usually a seven-day period, thus restricting hunters to harvesting only bull elk during the other part of the season. An either-sex partial dummy variable was created to capture the effect of

this either-sex partial season on hunter demand, with a value of one designated to these either-sex partial permits, a value of zero otherwise.

Some permits, designated unlimited license permits, allow an unlimited number of applicants to obtain the permit. During the hunting season, once a certain number of elk are harvested, all hunting under this special permit is stopped by MFWP. The harvest quota is set by MFWP and is either announced in the hunting regulations prior to the hunting season, or announced during the hunting season. Due to the complications with these permits, the unlimited license observations were dropped from the either-sex/bull-only hunter demand regressions.

Some either-sex and bull-only permits restrict hunters to harvesting brow-tined bull elk only, thus restricting the harvest of spike bulls. A brow-tined bull dummy variable was created to capture the effect of this regulation on hunter demand. A value of one was given for this dummy variable if the brow-tined only restriction accompanied a permit, a value of zero otherwise.

Some either-sex and bull-only permits restrict hunters to archery-only equipment to harvest an elk. An archery-only dummy variable was created with permits limiting hunters to using archery equipment only getting a value of one, and a value of zero otherwise.

The summary statistics for the variables used in the 2000, 2001, and 2002 hunter demand models are shown in tables C.7, C.8, and C.9 respectively, in Appendix C. The hunter demand model results for each year are shown in their respective columns in table 5.5.

Table 5.5. Either-sex/bull-only hunter demand model regression results.
Dependent Variable = Number of First Choice Applicants Per Permit Issued.

Variable	Year 2000	Year 2001	Year 2001
Constant	8.771**	6.955**	5.089*
	(3.780)	(2.677)	(2.719)
Percent Success of Harvesting a Bull Elk (lagged)	0.116***	0.128***	0.226***
	(0.040)	(0.032)	(0.036)
Number of Boone and Crockett Club Bulls	-4.112***	-3.339***	-1.322
	(1.272)	(0.984)	(1.035)
33 to 65 Percent Private Land	-0.340	-0.644	0.467
	(3.140)	(2.490)	(2.437)
66 to 100 Percent Private Land	2.574	0.144	-0.457
	(2.388)	(2.022)	(2.107)
Distance from Major Population Center	1.270	1.086	-0.842
	(0.793)	(0.721)	(0.725)
Youth Hunt Dummy	2.937	-1.484	12.034***
	(8.057)	(4.445)	(3.733)
Late Season Dummy	19.886***	7.815*	7.013**
	(5.989)	(4.201)	(3.508)
Early Season Dummy	No Observations	-12.016***	-2.999
		(4.045)	(4.486)
Bull-Only Permit Dummy	-6.356	-5.446	-5.106***
	(5.739)	(4.765)	(4.930)
Brow-tined Bull Antler Restriction Dummy	-4.033	-3.151	-1.951
	(2.582)	(1.922)	(1.946)
Archery-Only Dummy	-12.710**	No Observations	No Observations
	(5.230)		
Either-Sex Partial Season Dummy	-2.340	No Observations	No Observations
	(4.944)		
Southwest Montana Wolf Variables			
Initial Single District Wolf Pack Inhabitance Dummy	No Observations	4.219	4.449
		(4.992)	(3.678)
Initial Multiple-district Wolf Pack Inhabitance Dummy	-5.924	No Observations	2.146
	(4.294)		(3.901)
5-Year Average Wolf Population	-0.297	1.583	-0.018
	(1.935)	(1.273)	(0.772)
Difference from 5-Year Average Wolf Population	1.854	-0.006	-0.558
	(1.324)	(0.286)	(0.437)
Adjusted R-Squared	0.579	0.556	0.687
Standard Error of Regression	7.37	6.22	6.411
Observations	77	76	83

Notes: Standard errors are shown in parentheses under the coefficients. * Signifies significance at 10 percent confidence level. ** Signifies significance at 5 percent confidence level. *** Signifies significance at 1 percent confidence level.

The set of Southwest Montana Wolf Variables were not jointly significant at the 5 percent level in any of the hunter demand models. Many other variables were significant at the 5 percent confidence level. The percent success of harvesting a bull elk variable was positive and significant at the 1 percent confidence level in each model. The late season dummy variable had a significant positive impact on hunter demand in 2000 and 2002. The early season dummy variable was negative and significant at the 1 percent level in 2001. The number of Boone and Crocket Club Bulls variable was negative and significant at the 1 percent confidence level in 2000 and 2001. This result suggests that as the number of Boone and Crocket Club bulls increases, hunter demand decreases. As previously discussed, this variable is a very raw measure of antler quality. The negative coefficient on this variable in 2001 suggests that this variable may be picking up another affect not controlled for in the other variables included in the model. The youth hunt dummy variable was positive and significant at the 1 percent level in 2002. The bull-only dummy variable was negative and significant at the 1 percent confidence level in 2002. The constant was positive and significant at the 5 percent level in 2000 and 2001.

CHAPTER 6

ESTIMATED WOLF IMPACTS AND CONCLUSIONS

The reintroduction of the gray wolf into Yellowstone National Park in the mid-1990s, as well as the dispersal of wolves from Canada into the northern portions of Montana, has brought the wolf to the forefront of controversy in Montana. This controversy stems from the fact that those 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.

Hunters are another constituency group in Montana that are likely to be affected by wolves in diverse ways. While wolf predation will likely reduce big-game populations, hunters may gain a positive value from hunting in an area inhabited by wolves due to the added "wildness" of the area or the added opportunity of viewing a wolf while on a hunt. Hunters likely consider these conflicting values when choosing to oppose or support wolf recovery. While there have been numerous studies on wolf predation rates (Smith, Stahler, and Guernsey 2003) and the effects of wolf predation on elk distribution in the Northern Rocky Mountain Recovery Area (NRMRA) (Creel and Winnie 2004), as of 2005 there have been no studies on how wolf predation in Montana has directly affected hunters. Therefore, hunters taking a stance on wolf recovery in the NRMRA may do so based on incomplete information.

The impact of wolf recovery on state game agencies is also important. Montana Fish, Wildlife, and Parks' (MFWP) primary budget source is from hunting and fishing

license revenue (MFWP 2004, Annual Report 2003). If wolf predation reduces big-game populations, MFWP may experience significant reductions in hunter support and budget size. As of 2005, the number of wolves is currently exogenously determined for MFWP because wolf management is under federal control. The number of wolves will become endogenous, subject to constraints, if control of wolves is handed over to the state game agency (MFWP Final EIS 2003). Montana's wolf management plan, which was accepted by the USFWS in 2003, is set to manage wolves at the minimum allowable level of fifteen breeding pairs (MFWP Final EIS 2003). Since a breeding pair is only two wolves, MFWP may be able to exert intensive management on wolf pack sizes in Montana. Due to their reliance on license revenues, MFWP has the incentive to manage wolf pack sizes at low levels to limit their impact upon hunting revenue sources as well as hunter support.

Additional pressure to manage pack sizes at low levels might also come from agricultural interests. From 1987 to 2003, wolves within Montana have killed at least 155 cattle, 318 sheep, 22 dogs, and 9 other farm animals. During that same time period, 96 wolves were moved and 127 were killed because of wolf-livestock conflicts (USFWS 2004, 2003 Rocky Mountain Wolf Recovery Report).

While reduced hunting permit numbers and agricultural interests may exert pressure on MFWP to manage wolf pack sizes at low levels, it is unclear if hunters will exert similar pressure. Reductions in permit numbers will negatively affect hunter values. However, if hunters gain additional value from hunting in areas inhabited by wolves, the total affect on hunter values is unknown. Understanding the total effect of wolves on

hunter demand is vital information MFWP needs if placed in control of wolf management.

The goal of this thesis was to develop a method to analyze the impacts of wolves on big-game hunting in the NRMRA, and to use this method to estimate the impacts of wolves on elk hunters and game agency revenues in Montana. By creating an empirical method to analyze wolf impacts, and presenting the results of these impacts, we can understand hunters' relative weights over the costs and benefits of wolves. The estimates will also provide MFWP with information on how agency revenues are being affected by wolves and information on how hunters are adjusting in areas inhabited by wolves. The ability to properly forecast the impact of wolves on hunting license revenue will allow MFWP to forecast future revenue streams more accurately as wolves continue inhabiting other portions of the state.

Models were developed to assess the impact of wolves on the quality and quantity of limited elk hunting permits, hunter demand for these limited elk hunting permits, and the quality of general license hunting in Montana. Data from MFWP hunting and harvest reports, hunting regulations, wolf recovery annual reports, and other sources were used to construct the models in this thesis. The time period considered is from 1999 to 2002.

The likely diversity in the values hunters gain from various permits, as well as the biological differences between cow and bull elk, required the models used in this thesis to be tested separately for (1) cow permits and (2) either-sex and bull-only permits. A separate model was also used to test the impacts of wolves on general license elk hunting in Montana.

Estimating the outright quantity of hunting permits issued and the quality of these permits is more difficult than estimating the level of each hunting district's elk population. Additionally, accurate counts of the elk population levels are not available (MFWP Final EIS 2003, 48). Each hunting district's elk population is a complicated function of previous years' predation, weather variables, human effects, forest fire activity, food and water resources, other habitat information, and the district's size and hunting regulations. Due to the lack of adequate data needed to estimate the levels related to the elk population, the models used in this paper estimated the *change in* these elk permit quantity and quality variables rather than their levels. Using these change variables allowed for a more simple set of models to be used in estimating the impacts of wolves on big-game hunting in Montana.

Wolves could affect elk hunting in Montana in a number of ways, and the magnitudes of each impact are highly dependent upon the management strategies undertaken by MFWP. The predation and elk distributional effects of wolves on elk hunting and hunter demand are likely to differ with the wolf population size in a district, the length of time wolves have inhabited a hunting district, and the intensity at which the wolf population has grown in a district. Wolf variables were constructed to capture the effects of these potential differences in wolf impacts on elk hunting and hunter demand. Also, MFWP may respond to the impacts of wolves in a number of ways. If wolf predation reduces elk numbers, but MFWP holds constant the number of permits issued, then hunter harvest rates will likely be adversely affected. Hunters observing this MFWP

behavior will adjust their expectations of harvest rates in response, likely decreasing hunter demand. The opposite effect could be true as well.

Discussion with a wolf biologist, Ed Bangs, of the USFWS, suggested that wolves in different portions of the Montana should be treated differently in the empirical models (October 2004). Three different wolf populations were defined in Montana based on differences in prey composition and habitat. These areas were Northwest Montana, Central Montana, and the Southwest Montana. Distinctions were also made between wolf packs that inhabited a single hunting district versus wolf packs that inhabited two hunting districts. The wolf variables included in the models are initial existence dummy variables separated for single-district and multiple-district wolves, the five-year average wolf population, and the wolf population difference from the five-year average wolf population.

The predicted impacts reported in this chapter were obtained by multiplying each wolf-district observation's explanatory variable levels with the corresponding estimated model coefficients. For the change in permits issued and change in hunter harvest models the estimated observational impacts were then summed to obtain a total estimated impact on each dependent variable, as well as the total estimated revenue impacts on MFWP due to wolves. For the hunter demand models, the estimated impact of wolves on the number of applicants per permit was obtained by multiplying the wolf variable levels with their corresponding estimated coefficient. The reported wolf impact on applicants per permit was obtained by taking an average across each permit. The total revenue impacts in these hunter demand models were estimated by multiplying the estimated wolf impact on

applicants per permit by the number of permits issued for each permit type. The sum was then multiplied by the price of entering the lottery for a special permit.

Predicted Impacts of Wolves in Northwest Montana

The impacts of wolves on elk hunting in Northwest Montana are not expected to be as negative as those in other portions of the state. The composition of the wolf's diet in Northwest Montana is reported to be much different than that of wolves in other parts of the state, consisting of 83 percent white-tailed deer, 14 percent elk, and 3 percent moose (MFWP Final EIS 2003, 22). While there is wolf predation on elk in Northwest Montana, significant reductions in deer populations due to wolf predation may lead to short-run increases in elk populations. Also, wolf predation may affect elk distribution. If the distributional impacts of wolves on elk populations in Northwest Montana make elk more easily available to hunters or create more human-elk conflict, then the total short-run effect of wolves on elk may lead to increased hunter harvest and/or permit numbers. Due to these conflicting impacts, the expected sign of the total wolf impacts on elk hunting in Northwest Montana is unknown.

The model results estimated no significant impacts of wolves upon special permit hunter harvest or on general license hunter harvest in Northwest Montana. These results suggest that general license hunters and MFWP may be adjusting to the impacts of wolves on elk populations such that there are no additional impacts upon elk hunter harvest rates. In addition, there were no consistent impacts on hunter demand for cow permits in Northwest Montana from 2000 to 2002.

The set of Northwest Montana Wolf Variables in the change in the number of cow permits issued model are jointly significant at the 1 percent confidence level. The estimated wolf impacts on elk special permit quantity at their respective means as well as the wolf variable means are shown below in table 6.1.

Table 6.1. Northwest Montana 1999 to 2002 cow permit wolf-inhabited district variable means and estimated impact.

Variable	Mean/Estimated Impact
Explanatory Wolf Variables	
Wolf Inhabitance Years	5
Wolf Population Difference from 5-year Average	1.7
Five Year Average Wolf Population	4.4
Predicted Impacts of Wolves	
Estimated Total and Percentage Change in Permits Issued Due to Wolves	320 / 65% increase
Estimated Total Revenue Gain to MFWP Due to Wolves	$9,132
Wolf Impact as Percentage of Total Revenue from Wolf-Inhabited District Permits	38.6%

The total estimated impact of wolves in Northwest Montana on the quantity of cow elk permits issued from 1999 to 2002 is a positive 320 permits, which is a 65 percent increase in these wolf-inhabited districts. At the number of first choice applicants per permit for each observation, these permits created an additional $9,132 in revenue to MFWP from 1999 to 2002, a 38.6 percent increase.

Comparing the estimated observational impacts, as well as the estimated model coefficients, the data suggests that Northwest Montana wolves may have a positive effect in the early years of their inhabitance, and a small negative effect in later years of inhabitance (table 5.6). If the elk distributional effects of wolves cause more human conflict with elk, then these results would be consistent with MFWP adjusting permit

numbers positively in response to these effects. Also, significant reductions in deer populations due to wolf predation may cause short-run increases in the elk population. These positive short-run increases in the elk population may lead MFWP to increase permit numbers in response.

Predicted Impacts of Wolves in Central Montana

There were no jointly significant estimates for the set of Central Montana wolf variables in the change in cow permits issued model. However, the Central Montana wolf variables were jointly significant in the change in hunter harvest model at the 1 percent confidence level for these cow permits. These results suggest that although MFWP may not be adjusting permit numbers in response to wolves, hunter harvest is being affected. The 1999 to 2002 cow permit change in hunter harvest model variable means and predicted impacts are shown in table 6.2.

Table 6.2. Central Montana 1999 to 2002 cow permit wolf-inhabited district variable means and estimated impact.

Variable	Mean/Estimated Impact
Explanatory Wolf Variables	
Wolf Inhabitance Years	5.3
Wolf Population Difference from 5-year Average	1.3
Five Year Average Wolf Population	4.6
Predicted Impacts of Wolves	
Estimated Total and Percentage Change in Hunter Harvest Due to Wolves	-94 / 11% decrease

Since the models estimate that MFWP is not adjusting permit numbers in response to wolves in Central Montana, the results can be translated as the direct impact of wolves on cow-elk permit hunting quality in Central Montana. The estimated total

impact of wolves on cow permit hunter harvest from 1999 to 2002 in Central Montana hunting districts is a total reduction in hunter harvest of 94 cow elk, which is an 11 percent decrease. As previously discussed, due to the inconsistencies between the pooled models and the hunter demand models no estimated values of this loss of elk on hunters can be made.

The set of Central Montana wolf variables were not jointly significant in any of the cow permit hunter demand models. These results suggest that the marginal value of these cow permits and the revenue MFWP receives from these permits are not significantly being affected by wolves. However, since significant negative wolf impacts on hunter harvest were estimated, the lack of significance on the wolf variables in the hunter demand models can be interpreted two ways. First, these results may suggest that hunters are not adjusting their harvest rate expectations in response to wolves. Second, it may mean that hunters are adjusting their expectations of lower harvest rates but are willing to make the trade-off to hunt in a wolf-inhabited district due to the added value the wolf creates.

Table 6.3. Central Montana 1999 to 2002 general license wolf-inhabited district means and estimated impact.

Variable	Mean/Estimated Impact
Explanatory Wolf Variables	
Wolf Inhabitance Years	4.5
Wolf Population Difference from 5-year Average	2.1
Five Year Average Wolf Population	3.7
Predicted Impacts of Wolves	
Total and Percentage Estimated Change in Hunter Harvest Due to Wolves	-195 / 18% decrease

Another model where the Central Montana Wolf variables were jointly significant at the 1 percent confidence level was the change in hunter harvest model for general license elk permits. The means of the Central Montana Wolf Variables and the estimated wolf impacts for these 1999 to 2002 general license permits are shown in table 6.3.

The estimated total impact of wolves on general license elk hunter harvest in Central Montana from 1999 to 2002 is a negative 195 elk, which is an 18 percent decrease. This negative wolf impact could be viewed two ways. First, it is possible that hunters are not fully adjusting to negative impacts upon the elk population by transferring out of wolf-inhabited districts to other hunting districts. Second, it is also possible that hunters may place a positive value upon hunting in these wolf-inhabited areas and are willing to hunt in areas with lower success rates for the added value of hunting in a wolf inhabited area.

Predicted Impacts of Wolves in Southwest Montana

The Southwest Montana wolf variables were jointly significant at the 5 percent confidence level in seven of the eleven models estimated. This area was expected to have the largest wolf impact because it has a larger elk and wolf population than do the other areas of Montana.

The set of Southwest Montana Wolf Variables in both the change in cow permits issued model and change in cow permit hunter harvest model were jointly significant at the 1 percent confidence level. The wolf means and estimated impacts are shown in table 6.4.

Table 6.4. Southwest Montana 1999 to 2002 cow permit wolf-inhabited district variable means and estimated impacts.

Variable	Mean/Estimated Impact
Explanatory Wolf Variables	
Wolf Inhabitance Years	3.3
Wolf Population Difference from 5-year Average	7.5
Five Year Average Wolf Population	2.3
Predicted Impacts of Wolves	
Estimated Total and Percentage Change in Permits Issued Due to Wolves	-791 / 7% decrease
Total Estimated Wolf Impact on MFWP Revenues from Permit Change	-$9,423
Wolf Impact as Percentage of Total Revenue from Wolf-Inhabited District Permits	8.8% decrease
Estimated Total and Percentage Change in Hunter Harvest Due to Wolves	-553 / 15% decrease

The estimated total impact of wolves on the number of cow permits issued from 1999 to 2002 was a negative 791 permits, which is a 7 percent decrease. The corresponding estimated loss in revenue to MFWP from these permits was $9,423, an 8.8 percent decrease. In addition, while MFWP is adjusting permit numbers in response to wolf predation, the change in hunter harvest model results estimate that hunter harvest rates are still being affected. The estimated impact of wolves on cow permit hunter harvest in these Southwest Montana wolf-inhabited districts from 1999 to 2002 is a negative 553 cow elk, which is a 15 percent decrease in hunter harvest.

The cow permit hunter demand models estimated no significant wolf impact on the marginal value of cow permits and the revenue MFWP received from each of these permits from 2000 to 2002. However, as with the Central Montana cow permits there were significant negative wolf impacts on hunter harvest estimated from 1999 to 2002. Therefore the lack of significance of the Southwest Montana wolf variables in the hunter

demand models may mean that either hunters are not fully adjusting their expectations to incorporate the lower harvest rates in these wolf districts, or hunters are willing to accept the lower harvest rates due to the added value of hunting in a wolf-inhabited district.

No significant wolf impacts were estimated in the either-sex and bull-only change in permits issued model for the Southwest Montana wolf districts. However, while MFWP is holding permit numbers constant for these permits, significant impacts upon hunter harvest were estimated. The wolf means and impacts on the change in hunter harvest model for the Southwest Montana Wolf districts in this regression are shown in table 6.5.

Table 6.5. Southwest Montana 1999 to 2002 either-sex/bull-only wolf-inhabited district means and estimated impact.

Variable	Mean/Estimated Impact
Explanatory Wolf Variables	
Wolf Inhabitance Years	3.7
Wolf Population Difference from 5-year Average	5.8
Five Year Average Wolf Population	2.6
Predicted Impacts of Wolves	
Estimated Total and Percentage Change in Total Hunter Harvest Due to Wolves	204.5 / 11% increase
Estimated Total and Percentage Change in Bull Elk Hunter Harvest Due to Wolves	8.9 / 1.4% increase

The estimated total impact of wolves on hunter harvest for either-sex/bull-only permits from 1999 to 2002 is an increase of 205 total elk, which is an increase of 11 percent. The estimated increase in the number of bull elk harvested is 8.9, which is a 1.4 percent increase. These results suggest that the impact of wolves in these areas have a positive net effect on hunter harvest for these special permits. These results are consistent

with the elk distributional effects of wolves having a positive affect on hunter harvest from 1999 to 2002 in these either-sex/bull-only districts.

Significant differences exist between the either-sex/bull-only permits and the cow permits in the Southwest Montana that may explain the increases in either-sex/bull-only permit hunter harvest versus the decreases in cow permits issued and hunter harvest. Many of the cow permits in Southwest Montana are late season hunts. The elk harvested using these permits likely consist mostly of migratory elk wintering outside of Yellowstone National Park. However, most of the either-sex/bull-only permits consist of regular season hunts. The results of these models are consistent with the distributional effects of wolf predation within Yellowstone increasing early elk migration out of the park, which would increase the number of cow elk harvested in these either-sex/bull-only permit hunts. In addition, the significant reductions in cow permit numbers and elk harvested using these cow permits during the late season hunts is consistent with wolf predation on Yellowstone elk herds reducing hunter opportunities and permit quality in these Southwest Montana cow permits.

There were no significant impacts of wolves on either-sex/bull-only permit hunter demand from 2000 to 2002 estimated. However, since the models estimated that hunter harvest was positively impacted during this time period, the lack of joint significance of the wolf variables in the hunter demand models may mean that hunters did not adjust their expectations to incorporate these positive impacts of wolves on harvest rates, or that hunters did adjust their expectations but placed a negative value on hunting in these wolf-inhabited districts.

Conclusions

The estimation results of this thesis provide information on how wolves affect elk hunting, and how elk hunters in Montana and MFWP both react to the wolf's existence in Montana hunting districts. Differences in elk populations and the prey composition of wolves throughout the state also provide examples of how these wolf impacts differ in areas with different prey compositions.

In portions of Montana where wolves primarily prey on deer, the models estimated a generally positive short-run effect on the number of permits issued. However, the models estimated a negative impact on permits issued where wolves had inhabited a district for a longer period of time. In addition, there were no significant impacts on hunter harvest rates in this region for cow permits or general license hunting. These results suggest that hunters and game agency officials in these areas are able to properly predict the impact of wolves and adjust such that hunter harvest rates for elk are not affected. The models also estimated that wolves had no effect on the marginal value of cow elk permits in these areas to both hunters and the game agency.

In portions of the state where naturally occurring wolves prey primarily on elk, the models estimated that MFWP and general license hunters are not fully adjusting to negative impacts of wolves on cow permit and general license hunter harvest rates. However, this incomplete general license hunter adjustment, coupled with the lack of significant wolf impacts on the marginal value of cow permits in this region, may mean that hunters place an additional value on hunting in these wolf-inhabited areas and are

willing to accept the reduction in hunter harvest in order to hunt in one of these wolf-inhabited areas.

In portions of the state where introduced wolves prey primarily on elk, the models estimated that general license hunters are adjusting to wolf predation such that hunter harvest rates are not being additionally affected. However, it seems that MFWP is having a much more difficult time managing the elk permits issued in this region. For example, while MFWP does seem to be reducing the number of cow permits issued in this region, hunter harvest rates are still being negatively affected. The model results also suggest that the either-sex permits in this area, which allow hunters to hunt earlier in the season, experienced an increase in hunter harvest rates due to the distributional effects of wolves in the early years of their inhabitance of these districts.

The proportionally large estimated wolf impacts in Southwest Montana relative to those in with Northwest and Central Montana are consistent with the argument that naturally occurring wolves have less of an impact on elk populations than do introduced wolves. It may be that naturally occurring wolves provide more time for elk herds, hunters, and game agencies to adapt to wolf predation, and therefore have less of a dramatic impact on elk populations and hunter success. The results of this thesis are consistent with this argument.

Implications

This thesis establishes a method by which to analyze the impacts of wolves on the demand for big-game hunting and local game agency revenues. Providing big-game hunters and state game agencies with information about how a wolf population is likely

to affect them will help environmentalists, hunters, and game agency officials form proper expectations of the benefits and costs of wolves. This information is especially important to state game agencies that will likely gain control of wolf management. The budget structure of these agencies is such that their reliance on hunting license revenues will likely affect their management of wolf populations. If state game agencies are expected to manage wolf populations without bias, then these agencies must be compensated for the additional expenses incurred from wolf management and the lost hunting license revenue due to wolf predation.

Model Limitations

The limited data available for this thesis prohibited the use of an ideal model using a systems estimator to estimate the impacts of wolves on hunter demand and game agency revenues in Montana. Since the results of these models cannot be drawn together with confidence, this thesis cannot make any total revenue impacts of wolves on MFWP from 1999 to 2002. Also, the hunting and harvest data from 1996 to 1998, which is when wolves were first reintroduced into Yellowstone National Park, was not yet released by MFWP as of March of 2005. This data would likely be useful in estimating the initial effects of wolves in the Southwest Montana. It is possible that wolves in this area may have affected winter elk migrations from Yellowstone into Montana, but due to the lack of this data these impacts cannot be estimated.

The data used in this thesis was from 1999 to 2002, which are the early years of wolf inhabitance for most of the observed wolf-inhabited districts of Montana. Therefore,

the estimates produced by the models in this thesis are estimates of the short-run impacts of wolves and cannot be extrapolated to the long-run.

Another potential problem associated with the change in harvest and permits issued models is from spatial correlation. It is likely that the hunting district weather variables used in these models are spatially correlated by region. Spatial correlation between the district weather variables in these models would bias the standard errors, the expected direction of which is upward. Therefore, it is possible that the t-statistics in these models are biased downwards.

Suggestions for Future Research

The models developed in this thesis could also be used to estimate the impact of wolves on hunter demand and game agency revenues in Wyoming and Idaho, the two other states in the Northern Rocky Mountain Recovery Area. Also, once the 1996 to 1998 hunting and harvest data is released by MFWP, a longer time period may be considered in estimating the impact of wolves in Montana. The availability of data would also allow the models developed in this thesis to be used on each specific wolf region separately and a more accurate model to be used which would address the concerns previously discussed.

In addition, once wolves have been established in Montana for a longer period of time, these models may be used to estimate the impact of wolves on the “market” for big-game hunting in the long-run. It is likely that the long-run estimates would significantly differ from the short-run estimates produced in this thesis and further research will be necessary to estimate these impacts.

REFERENCES

"A Yellowstone Chronology." Defenders of Wildlife. Retrieved 23 February 2004, from http://www.defenders.org/wildlife/wolf/ynpchro.html.

Adams, Layne G. and L. David Mech. "Wolves and Caribou in Denali National Park, Alaska." National Biological Service, National Park Service-Alaska Region. Retrieved on 23 March 2004, from http://biology.usgs.gov/s+t/noframe/s037.htm.

Bangs, Ed. Telephone Interview. October 2004.

Barzel, Yoram. Economic Analysis of Property Rights: Second Edition. Cambridge, UK: Cambridge University Press, 1997.

Black Bear Hunting and Harvest Report: License Years 1997 to 2001. Montana Fish, Wildlife, and Parks. Helena, Montana, 22 October 2002.

Boone and Crockett Club. 2004. Trophy Query Results: American Typical Elk, 1980 to 2004, Montana USA. Retrieved from 1 June 2004, from https://www.boone-crockett.org/community/trophyDB/act_SearchCategory.asp?.com=TRO

Buschena, David .E., Terry L. Anderson, and Jerry L. Leonard. "Valuing Non-Market Goods: The Case of Elk Hunting in Colorado and Montana." *Journal of Environmental Economics and Management* (2001) 41: 33-43.

Champ, Patricia A., Kevin J. Boyle, and Thomas C. Brown (Eds.). (2003). A Primer on Nonmarket Valuation: The Hedonic Method. Dordrecht, The Netherlands: Laura O. Taylor, pgs: 331-393.

Champ, Patricia A., Kevin J. Boyle, and Thomas C. Brown (Eds.). (2003). A Primer on Nonmarket Valuation: The Travel Cost Method. Dordrecht, The Netherlands: George R. Parsons, pgs:269-239.

Creel, Scott and John A. Winnie Jr. "Responses of Elk Herd Size to Fine-Scale Spatial and Temporal Variation in the Risk of Predation by Wolves." Publication of Montana State University, Department of Ecology, 2004.

Elk Hunting and Harvest Report: License Year 1999. Montana Fish, Wildlife, and Parks. Helena, Montana.

Elk Hunting and Harvest Report: License Year 2000. Montana Fish, Wildlife, and Parks. Helena, Montana.

Elk Hunting and Harvest Report: License Year 2001. Montana Fish, Wildlife, and Parks. Helena, Montana, 25 July 2002.

Elk Hunting and Harvest Report: License Year 2002. Montana Fish, Wildlife, and Parks. Helena, Montana, 17 July, 2003.

Fix, Peter and John Loomis. The Economic Benefits of Mountain Biking at One of its Meccas: An Application of the Travel Cost Method to Mountain Biking in Moab, Utah. Retrieved on 8 March 2004, from www.imba.com/cgi-in/advprint/print.cgi.

Gevock, Nick. "Killer Wolf Packs Marked for Death." Bozeman Daily Chronicle 10 March 2004: A1+.

Glenn, Dave. "Wolves: A Hunter's View." ESPN Outdoors. Retrieved 26 January 2004, from http://espn.go.com/outdoors/conservation/columns/guest_columnist /1687871.html.

"Gray Wolf Biology and Status." International Wolf Center. 2000. Retrieved 3 April 2003, from http://wolf.wildlife.museum/wolves/learn/basic/wolfbasic.asp.

Gude, Justin and Bob Garrott. "Lower Madison Valley Wolf-Ungulate Research Project 2002-03 Annual Report." Publication of Montana State University, Department of Ecology, 2003.

Inside of Montana Fish, Wildlife, and Parks. Retrieved on 11 of May 2004, from http://www.fwp.state.mt.us/insidefwp/ourdepartment.asp.

Jones, Maury. "Wolves: An Outfitter's View." ESPN Outdoors. Retrieved 26 January 2004, from http://espn.go.com/outdoors/conservation/columns/guest_columnist /1687894.html.

Kay, Charles E. (1997). "Wolf Recovery, Political Ecology, and Endangered Species." *The Independent Institute*.

Magagna, Jim. "Wolves: A Rancher's View." ESPN Outdoors. Retrieved 26 January 2004, from http://espn.go.com/outdoors/conservation/columns/guest_columnist /1687913.html.

Mader, T.R. (1991). "Wolves and Hunting." Abundant Wildlife Society of North America. Retrieved January 21, 2004, from http://www.natureswolves.com/big-game/wolves_and_hunting.htm.

McMillon, Scott. "Elk…it's what's for Dinner." Bozeman Daily Chronicle 8 November 2003: A1+.

McMillon, Scott. “Late Hunt Shrinking.” Bozeman Daily Chronicle. 1 July 2003:A1+.

McMillon, Scott. “Migrating Wolves Complicate Wildlife Management.” Bozeman Daily Chronicle 11 January 2004: A3.

Mech, L. David, Thomas J. Meier, John W. Burch, and Layne G. Adams. 1995. Patterns of prey selection by wolves in Demali National Park, Alaska. Pages 231-244 in L.D. Carbyn, S.H. Fritts, and D.R. Seip, eds. Ecology and Conservation of Wolves in a Changing World. Proceedings of the Second North American Symposium on Wolves, Canadian Circumpolar Institute, Edmonton, Alberta. Occasional Publication 35. Jamestown, ND: Northern Prairie Wildlife Research Center Home Page. http://www.npwrc.usgs.gov/resource/2000/denali/denali.htm (Version 06JUL2000).

Mech, David L. and Rolf O. Peterson. “Wolf-Prey Relationships.” Wolves: Behavior, Ecology, and Conservation. Eds. L. David Mech and Luigi Boitani. Chicago: University of Chicago Press, 2003.

Montana 1999 Big Game Hunting Regulations: Deer and Elk. Montana Fish, Wildlife, and Parks. Helena, Montana. (1999).

Montana 2000 Big Game Hunting Regulations: Deer and Elk. Montana Fish, Wildlife, and Parks. Helena, Montana. (2000).

Montana 2001 Big Game Hunting Regulations: Deer and Elk. Montana Fish, Wildlife, and Parks. Helena, Montana. (2001).

Montana 2002 Big Game Hunting Regulations: Antelope, Deer, and Elk. Montana Fish, Wildlife, and Parks. Helena, Montana. (2002).

Montana 2003 Big Game Hunting Regulations: Deer, Elk, and Antelope. Montana Fish, Wildlife, and Parks. Helena, Montana. (2003).

Montana 2004 Black Bear Hunting Regulations. Montana Fish, Wildlife, and Parks. Helena, Montana. (2004).

Montana 2004 Big Game Hunting Regulations: Deer, Elk, and Antelope. Montana Fish, Wildlife, and Parks. Helena, Montana. (2004).

Montana Fish, Wildlife, and Parks Annual Report 2003. A Publication of Montana Fish, Wildlife, and Parks, 2004.

Montana Fish, Wildlife, and Parks. Final Environmental Impact Statement. March 12, 2003. Montana FWP, P.O. Box 200701, Helena MT.

Montana Fish, Wildlife, and Parks. Planning a Hunt: Land Ownership Map. Retrieved on 1 June 2004 from http://www.fwp.state.mt.us.

National Oceanic and Atmospheric Administration. 2000. Climatological Data Annual Summary: Montana 1999. Department of Commerce, U.S.A. Volume 102 Number 13, ISSN 0145-0395.

National Oceanic and Atmospheric Administration. 2001. Climatological Data Annual Summary: Montana 2000. Department of Commerce, U.S.A. Volume 103 Number 13, ISSN 0145-0395.

National Oceanic and Atmospheric Administration. 2002. Climatological Data Annual Summary: Montana 2001. Department of Commerce, U.S.A. Volume 104 Number 13, ISSN 0145-0395.

National Oceanic and Atmospheric Administration. 2003. Climatological Data Annual Summary: Montana 2002. Department of Commerce, U.S.A. Volume 105 Number 13, ISSN 0145-0395.

Nickerson, Peter H. (1990). "Demand for the Regulation of Recreation: The Case of Elk and Deer Hunting in Washington State." *Journal of Land Economics* 66: 437-447.

"Overview of Relationships Between Bears, Wolves, and Moose in Alaska." Alaska Department of Fish and Game. Retrieved on 19 April 2004, from http://wildlife.alaska.gov/management/planning/mcgrath/pred_prey.cfm.

Parker, Dominic Paul. (2001) "The Effects of Contracting Costs, Bureaucratic Costs, and Constituencies on State Wildlife Agency Budgets." A Publication of Montana State University, Department of Agricultural Economics and Economics.

"Potential Interactions Between Black Bears, Grizzly Bears and Grey Wolves in Yellowstone National Park." Retrieved January 21, 2004, from http://www.griztrax.net/.

"Questions and Answers about Moose, Wolves, and Bears in the McGrath Area." Alaska Department of Fish and Game. Retrieved on 6 April 2004, from http://wildlife.alaska.gov/management/planning/mcgrath/faq.cfm.

Rosen, William E. Red Wolf Recovery in Northeastern North Carolina and the Great Smoky Mountains National Park: Public Attitudes and Economic Impacts.

Publication of Cornell University, Department of Policy Analysis and Management, 1997.

Scrogin, David, Robert P. Berrens, and Alok. K. Bohara. (2000). "Policy Changes and the Demand for Lottery-Rationad Big Game Hunting Licenses." *Journal of Agricultural and Resource Economics*, 25(2): 501-519.

Smith, D.W., D.R. Stahler, and D.S. Guernsey. 2003. Yellowstone Wolf Project: Annual Report, 2002. National Park Service, Yellowstone Center for Resources, Yellowstone National Park, Wyoming, YCR-NR-2003-04.

Taylor, Justin and Thomas L. Marsh. (20003) "Valuing Characteristics of Transferable Deer Hunting Permits in Kansas." Paper prepared for presentation at the Western Agricultural Economics Association Annual Meeting, Denver, Colorado, 11 July 2003.

Thomas, Steve. "Wolves: The Sierra Club's View." ESPN Outdoors. Retrieved 26 January 2004, from http://espn.go.com/outdoors/conservation/columns/guest_columnist /1687901.html.

Tschida, Ron. "Elk Calf Numbers too Low." Bozeman Daily Chronicle 12 March 2004: A1+.

U.S. Fish and Wildlife Service. 1993. Montana Interagency Wolf Working Group 1993 Annual Report. USFWS, Ecological Services, 100 N. Park, Suite 320, Helena, MT.

U.S. Fish and Wildlife Service. 1994. Montana Interagency Wolf Working Group 1994 Annual Report. USFWS, Ecological Services, 100 N. Park, Suite 320, Helena, MT.

U.S. Fish and Wildlife Service. Final Environmental Impact Statement: The Reintroduction of Gray Wolves to Yellowstone National Park and Central Idaho. May, 1994. USFWS, Gray Wolf EIS, P.O. Box 8017, Helena MT.

U.S. Fish and Wildlife Service, Nez Perce Tribe, National Park Service, and USDA Wildlife Services. 1995. Rocky Mountain Wolf Recovery 1995 Annual Report. USFWS, Ecological Services, 100 N Park, Suite 320, Helena MT.

U.S. Fish and Wildlife Service, Nez Perce Tribe, National Park Service, and USDA Wildlife Services. 1996. Rocky Mountain Wolf Recovery 1996 Annual Report. USFWS, Ecological Services, 100 N Park, Suite 320, Helena MT.

U.S. Fish and Wildlife Service, Nez Perce Tribe, National Park Service, and USDA Wildlife Services. 2000. Rocky Mountain Wolf Recovery 1999 Annual Report. T. Meier, ed. USFWS, Ecological Services, 100 N Park, Suite 320, Helena MT.

U.S. Fish and Wildlife Service, Nez Perce Tribe, National Park Service, and USDA Wildlife Services. 2001. Rocky Mountain Wolf Recovery 2000 Annual Report. T. Meier, ed. USFWS, Ecological Services, 100 N Park, Suite 320, Helena MT.

U.S. Fish and Wildlife Service, Nez Perce Tribe, National Park Service, and USDA Wildlife Services. 2002. Rocky Mountain Wolf Recovery 2001 Annual Report. T. Meier, ed. USFWS, Ecological Services, 100 N Park, Suite 320, Helena MT.

U.S. Fish and Wildlife Service, Nez Perce Tribe, National Park Service, and USDA Wildlife Services. 2003. Rocky Mountain Wolf Recovery 2002 Annual Report. T. Meier, ed. USFWS, Ecological Services, 100 N Park, Suite 320, Helena MT.

U.S. Fish and Wildlife Service, Nez Perce Tribe, National Park Service, and USDA Wildlife Services. 2004. Rocky Mountain Wolf Recovery 2003 Annual Report. T. Meier, ed. USFWS, Ecological Services, 100 N Park, Suite 320, Helena MT.

Venkatachalam, L. (2004). The Contingent Valuation Method: A Review. *Environmental Impact Assessment Review*, 24, 89-124.

Vision, Mission, and Goals. Retrieved on 10 of May 2004, from http://fwp.state.mt.us/insidefwp/mission.asp.

"Wolf Restoration to Yellowstone." National Park Service. Retrieved 18 April 2003, from http://www.nps.gov/yell/nature/animals/wolf/wolfrest.html.

Yellowstone Wolf Project Annual Report 1997. A Publication of the National Park Service. Retrieved on 28 June 2004, from http://www.nps.gov/yell/nature/animals/wolf/wolfar97.pdf.

Yellowstone Wolf Project Annual Report 1998. A Publication of the National Park Service. Retrieved on 28 June 2004, from http://www.nps.gov/yell/nature/animals/wolf/wolfar98.pdf.

Yellowstone Wolf Project Annual Report 2002. A Publication of the National Park Service. Retrieved on 28 June 2004, from http://www.nps.gov/yell/nature/animals/wolf/wolfar02.pdf.

Zumbo, J. "A Howling in the West." *Outdoor Life* Dec. 2003: 70-74.

APPENDICES

APPENDIX A

LOTTERY ENTRANT EXPECTATIONS

APPENDIX A

LOTTERY ENTRANT EXPECTIONS

In the market description in Chapter 3, the demand for permit *j*, D_j^0, was the demand for obtaining permit *j* with certainty at each corresponding price. However, under the random lottery system a hunter rarely faces the opportunity to obtain a permit with certainty. Therefore each hunter takes the success of obtaining a permit into consideration when faced with the decision to enter a lottery. Thus, a lottery entrant expectations model must be developed first.

The cost of entering the lottery faced by each potential entrant is fixed at the application fee plus the license price. In figure A.4 this cost is shown as P_0.

As discussed earlier, the value a hunter receives from a permit is modeled to be a function of the permit characteristics and regulations. The expectation equilibrium is where the cost of entering the lottery for permit *j* will equal the marginal willingness to pay for the percent success of being drawn for permit *j*. The marginal willingness to pay curve for percent success of obtaining permit *j* is shown as $MWTP_0$ in figure A.4. $MWTP_0$ is the marginal willingness to pay for permit *j* assuming that the permit will produce the same characteristics and regulations as the previous year's permit provided. This curve can also be thought of as the MWTP curve for the previous year's applicants if they would have had perfect information last year. At $MWTP_0$, the percent success of being drawn for permit *j* of D_0 would be obtained by each lottery entrant at a cost of P_0. At this point the cost of entering the lottery for permit *j* is equal to the expected value of the marginal entrant in the lottery for permit *j*.

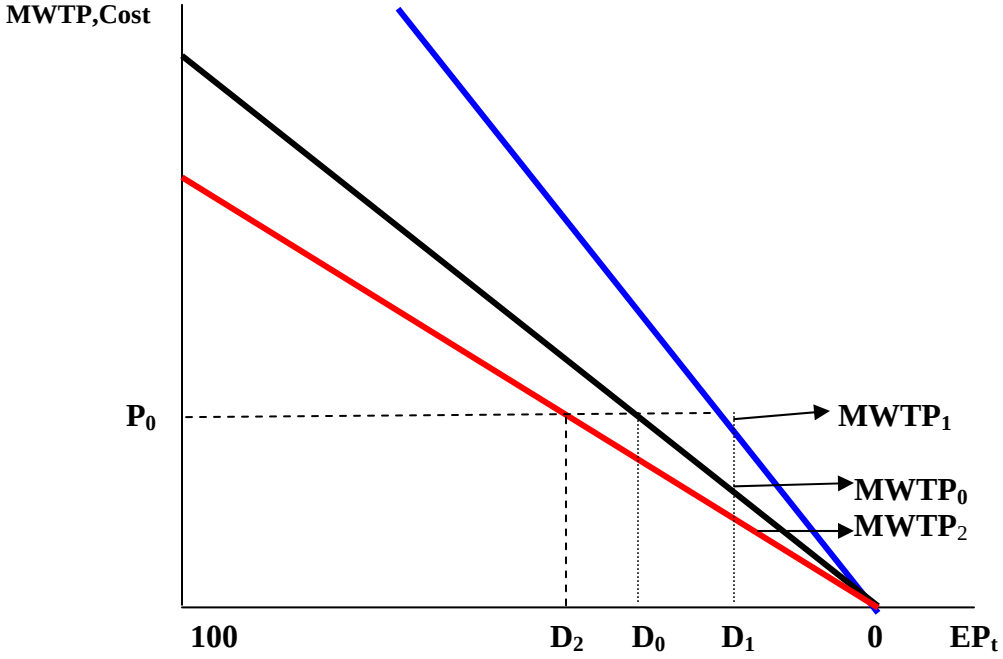
Much of the information a hunter receives about permit characteristics is based on the previous year's information. Also, the random lottery is structured such that each additional applicant into a lottery decreases the chances of all other lottery entrants to obtain a permit. Therefore a potential applicant must base his decision on whether to enter a lottery on his expectations of this year's permit characteristics, as well as the actions of other potential entrants into the lottery. An applicant's expectation of the probability of being drawn for permit *j* in year *t* can be thought of as the probability of being drawn for permit *j* the previous year, *(t-1)*, plus a change in the probability due to a change in the characteristics of permit *j* from year *(t-2)* to year *(t-1*). If an increase in valued characteristics were observed from year *(t-2)* to *(t-1)*, then the MWTP curve given perfect information of $MWTP_1$ would have been observed by last year's lottery entrants. However, applicants to last year's lottery may have gained rents because of the imperfect information they received. Given constant regulations, next year's lottery applicants MWTP curve will be $MWTP_1$ and the rents obtained by the previous year's applicants will be dissipated. Given a change in the permit characteristics from (t-2) to (t-1), potential lottery entrants in period t then form their expectations on the probability of obtaining a permit they might face given they choose to enter a lottery.

The same can be said if the permit characteristics obtained by the previous year's lottery entrants were worse than their expectations. Given perfect information, a MWTP curve of $MWTP_2$ would have been observed. Lottery entrants this year will have a MWTP curve of $MWTP_2$, with an increase chance of being drawn of D_2 expected.

From this approach an expectation model can be constructed to determine the actions of the marginal applicant. This thesis will assume that entrants into the lottery base their decision to enter on the expected probability (EP) of obtaining a permit. This probability expectation can be written as:

(A.1) $EP_t = EP_{t-1}$ + [the change in the characteristics from years (*t-2*) to (*t-1*) and the change in the restrictions from years (*t-1*) to *t*].

Figure A.4. Lottery applicant expectations graph.



Entrants basing their expectations in a similar fashion of this model capture rents received by the previous year's lottery entrants, and obtain the "expectation" equilibrium, where the expected cost of applying is equal to the expected value of applying to the marginal applicant. By assuming that hunters make their decisions to enter the lottery based on this model, we are able to use the actual lottery data from each year in order to

estimate the value the marginal applicant would receive from obtaining a permit from a given lottery.

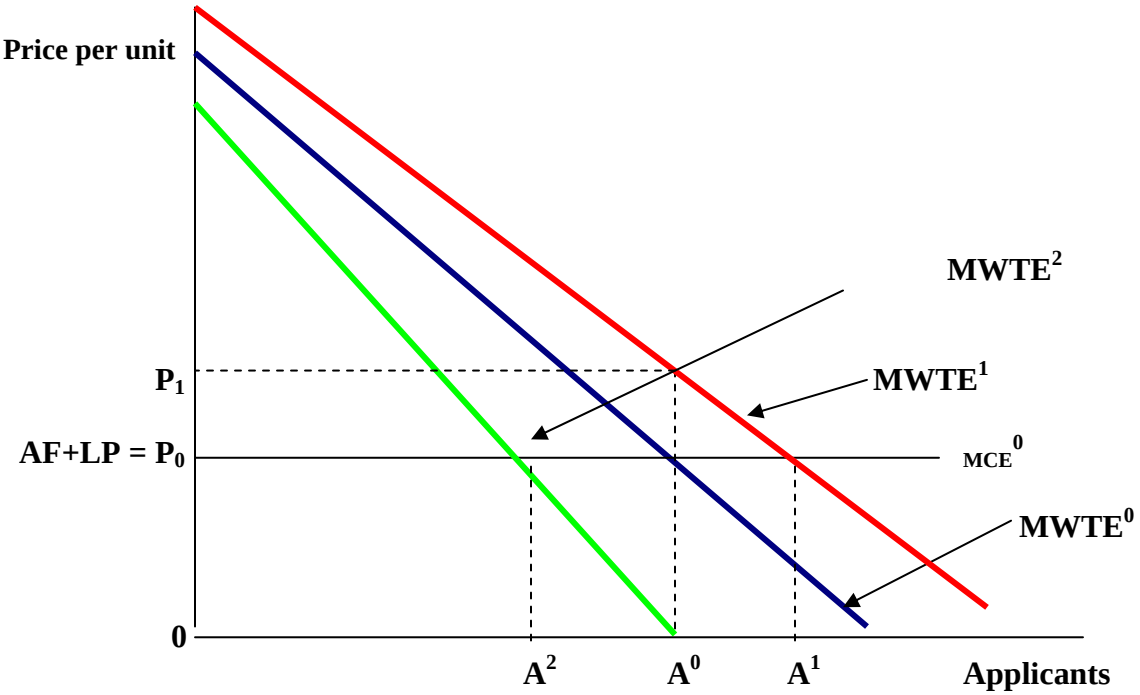
As discussed earlier, we know that the demand for a permit, permit *j*, is a function of the permit's characteristics and regulations. In addition, we assume that the demand for permit *j* is also a function of the expected probability of obtaining permit *j*. Thus, the demand for permit j can be written as a function of the vector of it's characteristics, $\underline{x}$, the vector of its regulations, $\underline{y}$, and the expected probability of obtaining permit *j* given that the choice has been made to enter the lottery for permit *j*.

The next issue is that permit *j* cannot be obtained with certainty, so describing the demand for permit *j* directly is not the appropriate way to look at the market. The good that lottery entrants are actually purchasing is not permit *j*, but the expected probability of obtaining permit *j*. We can now write the demand function as the demand for the expected probability of obtaining permit *j*. The demand can also be thought of as the marginal willingness to enter (MWTE) the lottery for permit *j*. The problem then arises of how to measure quantity demanded with a fixed number of permits. Since entry into lottery is restricted to one application per hunter, we can measure the quantity demanded as the number of applicants into the lottery for permit *j*. Thus the quantity demanded of the expected probability of obtaining permit *j* is simply the number of applicants for permit *j*.

Figure A.5 shows the market by which permits are allocated in the random lottery distribution scheme. The y-axis, which is labeled price per unit, measures the price of

entering into the lottery for permit *j*. P_0 is the price an applicant has to pay to enter into the lottery.

Figure A.5. Lottery applicant equilibrium.



The marginal willingness to enter (MWTE) curves represent the number of applicants willing to enter into the lottery for each corresponding price, given the expected probability of obtaining the permit, the *(t-1)* characteristics and the regulations associated with the permit from periods *(t-1)* to *t*. The equation for a given MWTE curve is shown in equation (A.2).

(A.2) Price = (Quota/Applicants){V(r, c)}

The quota divided by the number of applicants is the expected probability of obtaining the permit once entered into the lottery. The *V(r, c)* is the value the marginal hunter receives from obtaining the permit with *c* vector characteristics and *r* vector

regulations. The value an entrant would receive from obtaining a permit times the probability of obtaining the permit gives the price the marginal hunter is willing to pay to enter into the lottery for the permit.

If $MWTE^0$ were initially observed, then the corresponding number of applicants entering the lottery for the permit would be A^0, each paying P_0 to enter the lottery. If permit recipients attained better than expected characteristics, a higher MWTE curve, $MWTE^1$, will be next year's lottery entrants MWTE curve. If worse than expected characteristics are attained by this year's permit recipients, then a lower MWTE curve of $MWTE^1$ would be observed by next year's lottery entrants. By the market adjusting as described above, equilibrium is attained despite the distortions created in the primary market.

APPENDIX B

General Game Agency Support Model

APENDIX B

GENERAL GAME AGENCY SUPPORT MODEL

The constituent support theory allows an agency objective function to be defined. However, a few other considerations must be taken into account before a final objective function is established. First, the use of a one period model, where MFWP's objective is to maximize the support function for period t only, ignores the effect of MFWP's actions on future periods' constituent support. Many of the actions taken by MFWP to increase their constituent support in period *t*, such as increasing the number of hunting permits issued, would also reduce the constituent support they would receive in period *t+1*. The one period model would ignore these tradeoffs. The use of a two period model will take these multi-period trade-offs into consideration. These future effects will be discounted by a common discount factor (δ). The discounting term $\left(\frac{1}{1+\delta}\right)$ will be referred to as β in all further equations. The discount factor weighs the importance of future periods of constituent support and revenues relative to the current period, period *t*.

As previously discussed, license revenue from hunters and anglers constitutes a substantial proportion of MFWP's budget. It is likely that MFWP values the support from their constituent groups at differing weights, and the support function allows for differences in these weights. The weights for hunter support, recreationist support, and angler support are α_1, α_2, and α_3 respectively.

As previously discussed, there are many non-market dimensions on which the market for big-game hunting in Montana reaches equilibrium. In general license hunting,

each hunting district acts as a substitute district for all other hunting districts, thus changes in the characteristics of one hunting district will likely affect hunting in other districts as well. For example, if wolves reduce big-game populations in one district, hunters within that district will likely choose to hunt in a different district, or stop participating in the general hunting season entirely. The transfer of hunters from wolf-inhabited districts will likely reduce the marginal value of hunting in the other districts. The exiting of hunters from the market and transfer of hunters between districts will continue until the value of hunting for the marginal hunter is equal across districts and is equal to the costs of a general hunting license. Limited hunting permits also act as substitutes for one another. A reduction in the valued characteristics of one type of permit will lead applicants for that permit to transfer to other permit lotteries, or exit the permit market. The transfer and exit of applicants will occur until the marginal value of entering the lottery is equal for all permits and is equal to the expected cost of entering the lottery for a permit.

MFWP's consideration that game management policies in one district affect other hunting districts is built into the model using two constraints. The first constraint, $\left(\frac{i_j}{A_j\left(\underline{d}_t\right)}\right)V_j\left(\underline{d}_{jt}\right)=\left(\frac{i_k}{A_k\left(\underline{d}_t\right)}\right)V_k\left(\underline{d}_{kt}\right)=C_p$, is the limited permit market equilibrium condition that the value of entering the lottery for permit *j* for the marginal entrant is equal to the value of entering the lottery for permit *k*, which is equal to the expected cost (C_p) of entering the lottery for a permit. This value for the marginal hunter of entering the lottery for permit *j* is written as the value of permit *j* (V_j) multiplied by the odds of a successful draw (number of permits issued (i_j) divided by the number of lottery entrants)

for permit j (A_j). Because all hunting permits act as substitutes to one another, the number of lottery entrants for permit j is written as a function of the variables that impact hunter value in district j as well as the variables that impact hunter value in all other districts. The value of permit j is written as a function of the vector of variables that impact the value hunters receive from attaining permit j ($\underline{d}_{jt}$).

The second constraint, $G_{jt}\left(\underline{d}_{jt}, h_{jt}\left(\underline{d}_t\right)\right) = G_{kt}\left(\underline{d}_{kt}, h_{kt}\left(\underline{d}_t\right)\right) = C_g$, is the general hunting license equilibrium condition. The marginal value of hunting on a particular day (G_{jt}) in a given district, district j, is written as a function of the variables that impact the values hunters gain from hunting in district j ($\underline{d}_{jt}$), as well as the number of hunters that choose to hunt in district j (h_{jt}). Similar to the number of lottery entrants in the first constraint, the number of hunters in district j is written as a function of the variables that impact hunter value across all hunting districts. Equilibrium is attained when the marginal value of hunting is equal across all hunting districts on any given day.

Combining the constituent support equation with the constraints discussed above, a direct objective function can be established for MFWP. The direct objective function is shown in equation (B.1)

$$
\begin{aligned}
\max S = & \left[\alpha_1 H_t\left(\underline{d}_t\right) + \alpha_2 R_t\left(\underline{r}_t\right) + \alpha_3 A_t\left(\underline{a}_t\right)\right] \\
& + \beta\left[\alpha_1 H_{t+1}\left(\underline{d}_{t+1}\right) + \alpha_2 R_{t+1}\left(\underline{r}_{t+1}\right) + \alpha_3 A_{t+1}\left(\underline{a}_{t+1}\right)\right] \\
& subject\ to \left(\frac{i_j}{A_j\left(\underline{d}_t\right)}\right) V_j\left(\underline{d}_{jt}\right) = \left(\frac{i_k}{A_k\left(\underline{d}_t\right)}\right) V_k\left(\underline{d}_{kt}\right) = C_p \\
& and\ G_{jt}\left(\underline{d}_{jt}, h_{jt}\left(\underline{d}_t\right)\right) = G_{kt}\left(\underline{d}_{kt}, h_{kt}\left(\underline{d}_t\right)\right)
\end{aligned}
\tag{B.1}
$$

The relevant analysis for the context of this thesis is not the agency objective function itself, but how the wolf's presence in some Montana hunting districts impacts the objective function of MFWP, and more specifically the hunter support function. Assume for this discussion that wolves have first come to inhabit a district in Montana before the beginning of period *t* and that MFWP has the knowledge of wolves moving into and inhabiting the area prior to setting permit numbers in period *t*. As of 2005 wolves are still under federal control, therefore the impact of wolves will be analyzed as exogenous to MFWP. While the impacts of wolves must be taken as exogenous, MFWP can counter the effects of wolf predation by adjusting a number of variables, including the number of permits issued and the hunting regulations. By adjusting the number of permits and the hunting regulations optimally, MFWP can maximize its objective function in light of the impacts wolves may have in Montana.

The first impact of wolves in period *t* on the support function of MFWP comes through the hunter support function in period *t*. Wolf-inhabited hunting districts could be impacted in a number of ways. If MFWP were to set permit numbers without accounting for wolf predation, hunters would experience reduced harvest rates and possibly harvest quality in period *t*. This reduction in desired characteristics would reduce hunter support.

Alternatively, in anticipation to wolf predation MFWP might take a preemptive stance in game management and decrease permit numbers in period *t*. Such a reduction in permit numbers will reduce hunter support in period *t*. MFWP might also maintain permit numbers, but place additional harvest restrictions and reduce season days to further reduce harvest rates by hunters.

Hunters also gain value from viewing big-game and “could have harvested” encounters. If wolf predation reduces big-game populations, it will likely reduce the value hunter’s gain from these activities, thereby reducing hunter support. Wolves may also impact non-game populations. While some species may benefit from wolf predation, others may be negatively impacted, or directly reduced due to wolf predation. The total effect of this impact is impossible to determine.

Wolves could also affect hunter support if hunters place a value on the existence of wolves or viewing of wolves. Due to their conflicting interests, hunters could place a positive or negative existence value on wolves in Montana. Also, hunters might gain, or lose value from viewing a wolf while on a hunt. Therefore, total effect of these impacts is also difficult to determine.

Wolves in period t also affect the period $t+1$ hunter support function. Wolf predation in period t is likely to lead to a reduction in calf recruitment rates in period t, thereby reducing the harvestable game population in period $t+1$. Predation on adult game animals in period t further reduces the harvestable game population carried over to period $t+1$. The sum of these effects may lead to reductions in permits issued, or a reduction in harvest rates in period $t+1$, or a combination of both effects. Effects on non-game wildlife populations from wolves in period t also carry over into period $t+1$, the total effect of which is again impossible to determine.

Additional wolf effects on big game hunting come through impacts on hunter demand. Two main factors may impact hunter demand, and therefore agency revenue in period t. First, if hunters place additional positive value in hunting areas inhabited by

wolves, then hunter demand is likely to increase with wolves, thereby increasing agency support in period *t*. Second, if hunters expect wolf predation to reduce big-game harvest rates, then hunter expectations of year *t*'s hunt characteristics will likely lead to a decrease in hunter demand in wolf-inhabited districts. The decreased hunter demand will lead to a decrease in game agency support in period *t*. Also, if MFWP reduces permit numbers in period *t* to account for wolf predation, the lower permit numbers will decrease revenues received by MFWP in period *t*.

The effects of wolves on game populations in period *t+1* will depend on the agency's policy in period *t*. If MFWP reduces permit numbers in period *t* in a pre-emptive response to wolf predation, then the losses in elk populations from period *t* to *t+1* will likely be smaller than if no change in permits occurred. Under this type of policy, MFWP is just substituting wolf predation for hunter harvest, thereby reducing the effect of wolves on the game population in period *t+1*. However, if MFWP's policy is to uphold permit numbers, then there could be a number of effects of wolves in period *t* on the game population in period *t+1*. Hunter harvest under stable permit numbers combined with wolf predation in period *t* will reduce game populations in period *t+1* more drastically than the permit reduction policy. The reduction in the game population in period *t+1* will likely lead to a reduction in the number of permits issued as well as other characteristics valued by hunters in period *t+1*, thereby reducing hunter demand and agency support in period *t+1*.

Non-wolf-inhabited districts could also be impacted by wolves in other districts. Decreases in the number of permits issued or lower game harvest rates due to wolf

predation in wolf-inhabited districts would cause applicants to transfer into lotteries for permits in other districts or exit the market. Applicants transferring their lottery application would decrease the marginal value of entering those lotteries, *ceteris paribus*, and cause the marginal applicants in those lotteries to exit the market.

In response to reductions in permit numbers within wolf inhabited districts MFWP may seek other hunting opportunities to provide hunters, such as programs to increase hunter access to private land, or special tags in wolf and non-wolf inhabited districts to compensate losses in hunter support due to wolf predation. Similar impacts of wolves could occur in general license hunting. Hunters experiencing lower harvest rates in wolf-inhabited districts may choose to hunt in non-wolf districts. The additional hunters in the non-wolf districts would likely drive down the harvest rates within those districts. Hunter relocation would occur until the marginal value gained from hunting in wolf and non-wolf districts is equal and is equal to the cost of a general license.

Wolves would also affect the agency support function of MFWP through the recreationist support function. Wolves may impact the existence value of recreationists receive from wildlife, where wildlife includes both wolves and prey species. In addition, the game management policy of MFWP in response to the impacts of wolves will also affect recreationist support. If permit numbers are reduced, then recreationist value gained from game populations will be less affected than if permit numbers are held constant.

The impact of wolves also affects the constraint. Suppose initially that the number of hunters and permit lottery entrants remain constant. Wolves impact hunter value in two

ways. First, if hunters gain value from hunting in areas inhabited by wolves, then the presence of wolves would increase the marginal value of hunting in wolf inhabited districts. Lottery entrants and general license hunters would then transfer to the wolf-inhabited district, until the marginal values of entering the lottery for a permit in that district becomes equal to the marginal value in the other districts, and the marginal value of general license hunting equilibrates across wolf and non-wolf districts. The hunters leaving the other districts for the wolf-inhabited district would increase the marginal value of entering the lottery and general license hunting in the non-wolf inhabited districts.

The second impact of wolves on the constraints comes through the impacts of wolf predation. Wolf predation on big-game populations will reduce the value hunters gain from hunting permits and general license hunting in wolf-inhabited districts, ceteris paribus. Lottery entrants and general license hunters will then transfer to other districts, thereby increasing the marginal value of entering the lottery for a permit in the wolf-inhabited district and increasing the marginal value of general license hunting in the district. Lottery entrants and general license hunters will transfer districts until the marginal value of entering the lottery and general license hunting is equal across all hunting districts. The total impact of this effect will reduce the marginal value of entering a lottery for a limited hunting permit and reduce the marginal value of participating in general license hunting in all hunting districts.

The total effect on both of the constraints depends on the relative size of the added existence value to the impact of wolf predation. In the discussion above there was

assumed to be a fixed number of hunters and lottery entrants in the market, however general license hunters and lottery entrants are able to freely enter and exit the market. If the total effect of wolves on hunter values in wolf-inhabited districts is negative, then the marginal value of entering the lottery for permits and the value hunters gain from general license hunting in all districts will decrease. The expected decrease will cause hunters and lottery entrants to leave the market until there respective marginal values equal their marginal costs. The opposite effect will occur if the wolf has a positive total impact on hunter values.

If wolf management becomes a choice variable to MFWP, the agency should weigh the costs and benefits of additional wolves. As noted previously, if MFWP gains control of wolf management, they would do so subject to a minimal wolf breeding pairs constraint. Therefore in constructing the support function of MFWP treating wolves as a choice variable, it would be appropriate to add a minimal wolf constraint that MFWP must adhere to in order to keep control of wolf management in Montana. Considering the trade-offs, MFWP can manage wolves as to maximize their constituent support function.

APPENDIX C

VARIABLE STATISTICAL TABLES

APPENDIX C

VARIABLE STATISTICAL TABLES

Table C.1: 1999 to 2002 Cow permit variable summary statistics.

Variable	Mean	Median	Maximum	Minimum	Std. Dev.	Observations
Number of Permits Issued (lagged)	139.073	100.000	2880.000	0.000	230.664	427
Change in the Number of Permits Issued	-.902	0.00	200	-500	50.861	427
Change in Harvest	0.012	1.000	340.000	-314.000	32.042	427
Total Harvest (lagged)	37.845	21.000	1082.000	0.000	82.388	427
Percent Change in the Number of Permits Issued	7.597	0.000	300.000	-93.333	39.769	427
Black Bear Harvest (lagged)	7.343	5.600	86.000	0.000	9.072	427
January-March Precipitation	2.337	1.800	13.500	0.100	1.923	427
January-March Precipitation Squared	9.153	3.240	182.250	0.010	18.817	427
April-August Precipitation	7.447	7.300	14.700	2.100	2.610	427
January-March Average Temperature	27.785	27.667	36.667	15.000	4.710	427
Change in October Precipitation	-0.155	-0.200	2.900	-3.700	1.322	427
Change in November Precipitation	-0.087	0.000	2.100	-4.800	0.775	427
Change in December Precipitation*Lateseason Dummy	-0.026	0.000	1.800	-3.100	0.337	427
Change in September Temperature	1.363	2.000	9.000	-6.000	3.702	427
Change in October Temperature	-2.314	-2.000	6.000	-10.000	3.290	427
Change in November Temperature	-1.763	-3.000	18.000	-22.000	12.635	427
Change in December Temperature*Lateseason Dummy	0.091	0.000	10.000	-7.000	1.718	427
Northwest Montana Wolf Variables						
Initial Single District Wolf Pack Inhabitance Dummy	0.012	0.000	1.000	0.000	0.108	427
Initial Multiple-district Wolf Pack Inhabitance Dummy	0.007	0.000	1.000	0.000	0.084	427
Five Year Average Wolf Numbers	0.124	0.000	8.500	0.000	0.957	427
Wolf Number Difference from 5 Year Average	0.047	0.000	9.400	-5.500	0.887	427

Table C.1: 1999 to 2002 Cow permit variable summary statistics (continued).

Variable	Mean	Median	Maximum	Minimum	Std. Dev.	Observations
Central Montana Wolf Variables						
Initial Single District Wolf Pack Inhabitance Dummy	0.019	0.000	1.000	0.000	0.136	427
Initial Multiple-district Wolf Pack Inhabitance Dummy	0.009	0.000	1.000	0.000	0.096	427
Five Year Average Wolf Numbers	0.281	0.000	9.000	0.000	1.483	427
Wolf Number Difference from 5 Year Average	0.081	0.000	6.500	-3.400	0.670	427
Southwest Montana Wolf Variables						
Initial Single District Wolf Pack Inhabitance Dummy	0.005	0.000	1.000	0.000	0.068	427
Initial Multiple-district Wolf Pack Inhabitance Dummy	0.014	0.000	1.000	0.000	0.118	427
Five Year Average Wolf Population	0.092	0.000	5.400	0.000	0.600	427
Wolf Number Difference from 5 Year Average	0.299	0.000	22.300	0.000	1.918	427

Table C.2. 1999 to 2002 Either-Sex/bull-only variable summary statistics.

Variable	Mean	Median	Maximum	Minimum	Std. Dev.	Observations
Southwest Montana Wolf Variables						
Initial Single District Wolf Pack Inhabitance Dummy	0.023	0.000	1.000	0.000	0.151	257
Initial Multiple-district Wolf Pack Inhabitance Dummy	0.043	0.000	1.000	0.000	0.203	257
Wolf Number Difference from 5 Year Average Wolf Population	1.157	0.000	24.100	0.000	3.611	242
Five Year Average Wolf Population	0.531	0.000	5.400	0.000	1.314	242
Other Model Variables						
Black Bear Harvest (lagged)	3.784	3.570	14.000	0.000	3.186	242
January-March Precipitation	2.018	1.500	9.400	0.100	1.833	242
January-March Precipitation Squared	7.417	2.250	88.360	0.010	16.547	242
April-August Precipitation	7.991	8.050	14.700	2.100	2.906	242
January-March Average Temperature	25.424	26.333	36.667	15.000	5.095	242
Change in October Precipitation	-0.064	0.000	4.000	-3.600	1.265	242
Change in November Precipitation	-0.004	0.000	1.000	-1.400	0.445	242

Table C.2. 1999 to 2002 Either-sex/bull-only variable summary statistics (continued).

Variable	Mean	Median	Maximum	Minimum	Std. Dev.	Observations
Change in December Precipitation*Lateseason Dummy	-0.046	0.000	1.800	-3.100	0.462	242
Change in September Temperature	1.244	2.000	7.000	-5.000	3.665	242
Change in October Temperature	-2.620	-3.000	5.000	-10.000	3.413	242
Change in November Temperature	-3.029	-6.000	18.000	-22.000	14.031	242
Change in December Temperature*Lateseason Dummy	-0.107	0.000	4.000	-7.000	1.204	242
Percent Change in the Number of Permits Issued	3.199	0.000	150.000	-80.000	20.720	242
Change in the Number of Permits Issued	0.669	0.000	200.000	-100.000	20.578	242
Number of Permits Issued (lagged)	172.388	62.5	1200	0	228.087	242
Change in Harvest	-0.360	1.000	215.000	-316.000	48.216	242
Total Harvest (lagged)	53.326	25.000	619.000	0.000	78.294	242

Table C.3. 1999 to 2002 General license model variable summary statistics.

Variable	Mean	Median	Maximum	Minimum	Std. Dev.	Observations
Change in Harvest	7.909	3.000	198.000	-216.000	49.243	405
Total Harvest (lagged)	73.373	57.000	363.000	0.000	71.806	405
Percent Change in the Number of Hunters	6.747	0.496	437.838	-76.190	42.137	405
Black Bear Harvest (lagged)	7.159	4.920	86.000	0.000	9.240	405
January-March Precipitation	2.460	1.900	13.500	0.100	2.059	405
January-March Precipitation Squared	10.283	3.610	182.250	0.010	20.667	405
April-August Precipitation	7.295	7.000	14.700	2.100	2.473	405
January-March Average Temperature	27.471	27.333	36.667	15.000	4.381	405
Change in September Precipitation	0.191	0.300	2.100	-2.200	0.778	405
Change in October Precipitation	-0.132	-0.100	4.000	-3.700	1.354	405
Change in November Precipitation	-0.095	0.000	2.100	-4.800	0.764	405
Change in September Temperature	1.319	2.000	9.000	-6.000	3.813	405

Table C.3. 1999 to 2002 General license model variable summary statistics (continued).

Variable	Mean	Median	Maximum	Minimum	Std. Dev.	Observations
Change in October Temperature	-2.400	-2.000	6.000	-10.000	3.412	405
Change in November Temperature	-1.938	-3.000	18.000	-22.000	12.614	405
Northwest Montana Wolf Variables						
Initial Single District Wolf Pack Inhabitance Dummy	0.017	0.000	1.000	0.000	0.130	405
Initial Multiple-district Wolf Pack Inhabitance Dummy	0.010	0.000	1.000	0.000	0.099	405
Five Year Average Wolf Numbers	0.200	0.000	15.900	0.000	1.512	405
Wolf Number Difference from 5 Year Average	0.053	0.000	9.400	-8.600	1.022	405
Central Montana Wolf Variables						
Initial Single District Wolf Pack Inhabitance Dummy	0.012	0.000	1.000	0.000	0.111	405
Initial Multiple-district Wolf Pack Inhabitance Dummy	0.007	0.000	1.000	0.000	0.086	405
Five Year Average Wolf Numbers	0.120	0.000	9.000	0.000	0.980	405
Wolf Number Difference from 5 Year Average	0.067	0.000	8.000	-3.600	0.634	405
Southwest Montana Wolf Variables						
Initial Single District Wolf Pack Inhabitance Dummy	0.012	0.000	1.000	0.000	0.111	405
Initial Multiple-district Wolf Pack Inhabitance Dummy	0.025	0.000	1.000	0.000	0.155	405
Five Year Average Wolf Population	0.127	0.000	7.900	0.000	0.741	405
Wolf Number Difference from 5 Year Average Wolf Population	0.242	0.000	13.200	-3.400	1.338	405

Table C.4. 2000 Cow permit hunter demand variable summary statistics.

Variable	Mean	Median	Maximum	Minimum	Std. Dev.	Observations
First Choice Applicants Per Permit	2.240	1.424	16.500	0.033	2.493	137
Late Season Dummy	0.102	0.000	1.000	0.000	0.304	137
Early Season Dummy	0.044	0.000	1.000	0.000	0.205	137
A7 License Dummy	0.146	0.000	1.000	0.000	0.354	137
Multiple-district Dummy	0.066	0.000	1.000	0.000	0.249	137
Distance from Major Population Center	1.341	1.000	5.500	0.000	1.160	137

Table C.4. 2000 Cow permit hunter demand variable summary statistics (continued).

Variable	Mean	Median	Maximum	Minimum	Std. Dev.	Observations
33 to 65 Percent Private Land	0.197	0.000	1.000	0.000	0.399	137
66 to 100 Percent Private Land	0.358	0.000	1.000	0.000	0.481	137
Percent Success of Harvest (lagged)	29.632	26.200	87.100	0.000	17.231	137
Northwest Montana Wolf Variables						
Difference in Wolf Population from 5 year Average	0.107	0.000	9.400	0.000	0.919	137
5 Year Average Wolf Population	0.064	0.000	7.200	0.000	0.629	137
Central Montana Wolf Variables						
Difference in Wolf Population from 5 year Average	-0.004	0.000	0.000	-0.200	0.029	137
5 Year Average Wolf Population	0.289	0.000	9.000	0.000	1.500	137
Southwest Montana Wolf Variables						
Initial Multiple-district Wolf Pack Inhabitance Dummy	0.044	0.000	1.000	0.000	0.205	137
Difference in Wolf Population from 5 year Average	0.235	0.000	10.100	0.000	1.147	137
5 Year Average Wolf Population	0.035	0.000	2.900	0.000	0.295	137

Table C.5. 2001 Cow permit hunter demand variable summary statistics.

Variable	Mean	Median	Maximum	Minimum	Std. Dev.	Observations
First Choice Applicants Per Permit	1.800	1.275	9.900	0.060	1.643	136
Late Season Dummy	0.096	0.000	1.000	0.000	0.295	136
Early Season Dummy	0.059	0.000	1.000	0.000	0.236	136
A7 License Dummy	0.206	0.000	1.000	0.000	0.406	136
Multiple-district Dummy	0.081	0.000	1.000	0.000	0.274	136
Distance from Major Population Center	1.246	1.000	5.000	0.000	1.051	136
33 to 65 Percent Private Land	0.206	0.000	1.000	0.000	0.406	136
66 to 100 Percent Private Land	0.324	0.000	1.000	0.000	0.470	136
Percent Success of Harvest (lagged)	42.249	39.850	94.100	0.000	19.030	136
Northwest Montana Wolf Variables						
Initial Single District Wolf Pack Inhabitance Dummy	0.007	0.000	1.000	0.000	0.086	136
Difference in Wolf Population from 5 year Average	-0.021	0.000	3.000	-3.500	0.508	136
5 Year Average Wolf Population	0.153	0.000	8.500	0.000	1.074	136
Central Montana Wolf Variables						
Initial Multiple-district Wolf Pack Inhabitance Dummy	0.015	0.000	1.000	0.000	0.121	136

Table C.5. 2001 Cow permit hunter demand variable summary statistics (continued).

Variable	Mean	Median	Maximum	Minimum	Std. Dev.	Observations
Central Montana Wolf Variables						
Difference in Wolf Population from 5 year Average	0.094	0.000	3.600	0.000	0.542	136
5 Year Average Wolf Population	0.296	0.000	9.000	0.000	1.526	136
Southwest Montana Wolf Variables						
Initial Single District Wolf Pack Inhabitance Dummy	0.007	0.000	1.000	0.000	0.086	136
Difference in Wolf Population from 5 year Average	0.493	0.000	22.300	0.000	2.863	136
5 Year Average Wolf Population	0.103	0.000	4.700	0.000	0.580	136

Table C.6. 2002 Cow permit hunter demand variable summary statistics.

Variable	Mean	Median	Maximum	Minimum	Std. Dev.	Observations
First Choice Applicants Per Permit	1.642	1.271	9.300	0.053	1.444	142
Late Season Dummy	0.127	0.000	1.000	0.000	0.334	142
Early Season Dummy	0.077	0.000	1.000	0.000	0.268	142
A7 License Dummy	0.211	0.000	1.000	0.000	0.410	142
Multiple-district Dummy	0.092	0.000	1.000	0.000	0.289	142
Distance from Major Population Center	1.169	1.000	5.000	0.000	0.942	142
33 to 65 Percent Private Land	0.197	0.000	1.000	0.000	0.399	142
66 to 100 Percent Private Land	0.380	0.000	1.000	0.000	0.487	142
Percent Success of Harvest (lagged)	31.301	28.150	87.100	0.000	16.989	142
Northwest Montana Wolf Variables						
Initial Single District Wolf Pack Inhabitance Dummy	0.028	0.000	1.000	0.000	0.166	142
Initial Multiple-district Wolf Pack Inhabitance Dummy	0.021	0.000	1.000	0.000	0.144	142
Difference in Wolf Population from 5 year Average	0.058	0.000	8.000	-5.500	1.144	142
5 Year Average Wolf Population	0.163	0.000	8.500	0.000	1.127	142
Central Montana Wolf Variables						
Initial Single District Wolf Pack Inhabitance Dummy	0.056	0.000	1.000	0.000	0.231	142
Initial Multiple-district Wolf Pack Inhabitance Dummy	0.007	0.000	1.000	0.000	0.084	142
Difference in Wolf Population from 5 year Average	0.143	0.000	6.500	-3.400	1.018	142
5 Year Average Wolf Population	0.283	0.000	9.000	0.000	1.494	142

Table C.6. 2002 Cow permit hunter demand variable summary statistics (continued).

Variable	Mean	Median	Maximum	Minimum	Std. Dev.	Observations
Southwest Montana Wolf Variables						
Initial Single District Wolf Pack Inhabitance Dummy	0.007	0.000	1.000	0.000	0.084	142
Difference in Wolf Population from 5 year Average	0.201	0.000	11.600	0.000	1.393	142
5 Year Average Wolf Population	0.144	0.000	5.400	0.000	0.821	142

Table C.7. 2000 Either-sex and bull-only permit hunter demand variable summary statistics.

Variable	Mean	Median	Maximum	Minimum	Std. Dev.	Observations
First Choice Applicants	406.831	248.000	3552.000	23.000	619.525	83
Advertised Quota	161.325	50.000	1000.000	0.000	217.129	83
Total Harvest (lagged)	41.639	19.000	251.000	0.000	52.778	83
Either-Sex Partial Dummy	0.036	0.000	1.000	0.000	0.188	83
Youth Hunt Dummy	0.012	0.000	1.000	0.000	0.110	83
Unlimited License Dummy	0.072	0.000	1.000	0.000	0.261	83
Percent Success of Harvesting a Bull	26.537	9.153	100.000	0.000	31.053	83
33 to 65 Percent Private Land	0.120	0.000	1.000	0.000	0.328	83
66 to 100 Percent Private Land	0.554	1.000	1.000	0.000	0.500	83
Distance from Major Population Center	1.937	1.500	5.500	0.000	1.522	83
Late Season Dummy	0.048	0.000	1.000	0.000	0.215	83
Archery-Only Dummy	0.108	0.000	1.000	0.000	0.313	83
Brow-tined Bull Antler Restriction Dummy	0.325	0.000	1.000	0.000	0.471	83
Bull-Only Permit Dummy	0.024	0.000	1.000	0.000	0.154	83
Number of Boone and Crockett Club Bulls	1.349	1.000	3.000	0.000	0.981	83
Southwest Montana Wolf Variables						
Initial Multiple-district Wolf Pack Inhabitance Dummy	0.084	0.000	1.000	0.000	0.280	83
5-Year Average Wolf Population	0.288	0.000	2.900	0.000	0.752	83
Difference from 5-Year Average Wolf Population	0.507	0.000	6.100	0.000	1.291	83

Table C.8. 2001 Either-sex and bull-only permit hunter demand variable summary statistics.

Variable	Mean	Median	Maximum	Minimum	Std. Dev.	Observations
First Choice Applicants	399.842	198.500	3460.000	5.000	581.008	82
Advertised Quota	171.720	62.500	1200.000	0.000	236.193	82
Total Harvest (lagged)	45.793	25.500	307.000	0.000	57.620	82
Percent Success of Harvesting a Bull	28.633	10.893	100.000	0.000	30.656	82
33 to 65 Percent Private Land	0.159	0.000	1.000	0.000	0.367	82
66 to 100 Percent Private Land	0.488	0.000	1.000	0.000	0.503	82
Distance from Major Population Center	1.805	1.500	5.500	0.000	1.475	82
Number of Boone and Crockett Club Bulls	1.341	1.000	3.000	0.000	0.984	82
Youth Hunt Dummy	0.037	0.000	1.000	0.000	0.189	82
Late Season Dummy	0.085	0.000	1.000	0.000	0.281	82
Early Season Dummy	0.110	0.000	1.000	0.000	0.315	82
Bull-Only Permit Dummy	0.024	0.000	1.000	0.000	0.155	82
Unlimited License Dummy	0.073	0.000	1.000	0.000	0.262	82
Brow-tined Bull Antler Restriction Dummy	0.378	0.000	1.000	0.000	0.488	82
Southwest Montana Wolf Variables						
Initial Wolf Pack Inhabitance Dummy	0.022	0.000	1.000	0.000	0.149	89
5-Year Average Wolf Population	1.978	0.000	24.100	0.000	5.410	82
Difference from 5-Year Average Wolf Population	0.498	0.000	4.700	0.000	1.204	82

Table C.9. 2002 Either-sex and bull-only permit hunter demand variable summary statistics.

Variable	Mean	Median	Maximum	Minimum	Std. Dev.	Observations
First Choice Applicants	365.824	188.000	3781.000	6.000	594.757	85
Advertised Quota	181.506	75.000	1200.000	0.000	232.737	85
Total Harvest (lagged)	44.506	25.000	307.000	0.000	56.544	85
Percent Success of Harvesting a Bull	24.116	8.017	100.000	0.000	29.684	85
33 to 65 Percent Private Land	0.153	0.000	1.000	0.000	0.362	85
66 to 100 Percent Private Land	0.506	1.000	1.000	0.000	0.503	85
Distance from Major Population Center	1.541	1.500	5.500	0.000	1.286	85
Number of Boone and Crockett Club Bulls	1.447	2.000	3.000	0.000	0.906	85

Table C.9. 2002 Either-sex and bull-only permit hunter demand variable summary statistics (continued).

Variable	Mean	Median	Maximum	Minimum	Std. Dev.	Observations
Youth Hunt Dummy	0.059	0.000	1.000	0.000	0.237	85
Late Season Dummy	0.118	0.000	1.000	0.000	0.324	85
Early Season Dummy	0.047	0.000	1.000	0.000	0.213	85
Bull-Only Permit Dummy	0.024	0.000	1.000	0.000	0.152	85
Unlimited License Dummy	0.024	0.000	1.000	0.000	0.152	85
Brow-tined Bull Antler Restriction Dummy	0.424	0.000	1.000	0.000	0.497	85
Southwest Montana Wolf Variables						
Initial Single District Wolf Pack Inhabitance Dummy	0.047	0.000	1.000	0.000	0.213	85
Initial Multiple-district Wolf Pack Inhabitance Dummy	0.047	0.000	1.000	0.000	0.213	85
5-Year Average Wolf Population	0.752	0.000	5.400	0.000	1.709	85
Difference from 5-Year Average Wolf Population	0.948	0.000	11.600	0.000	2.592	85