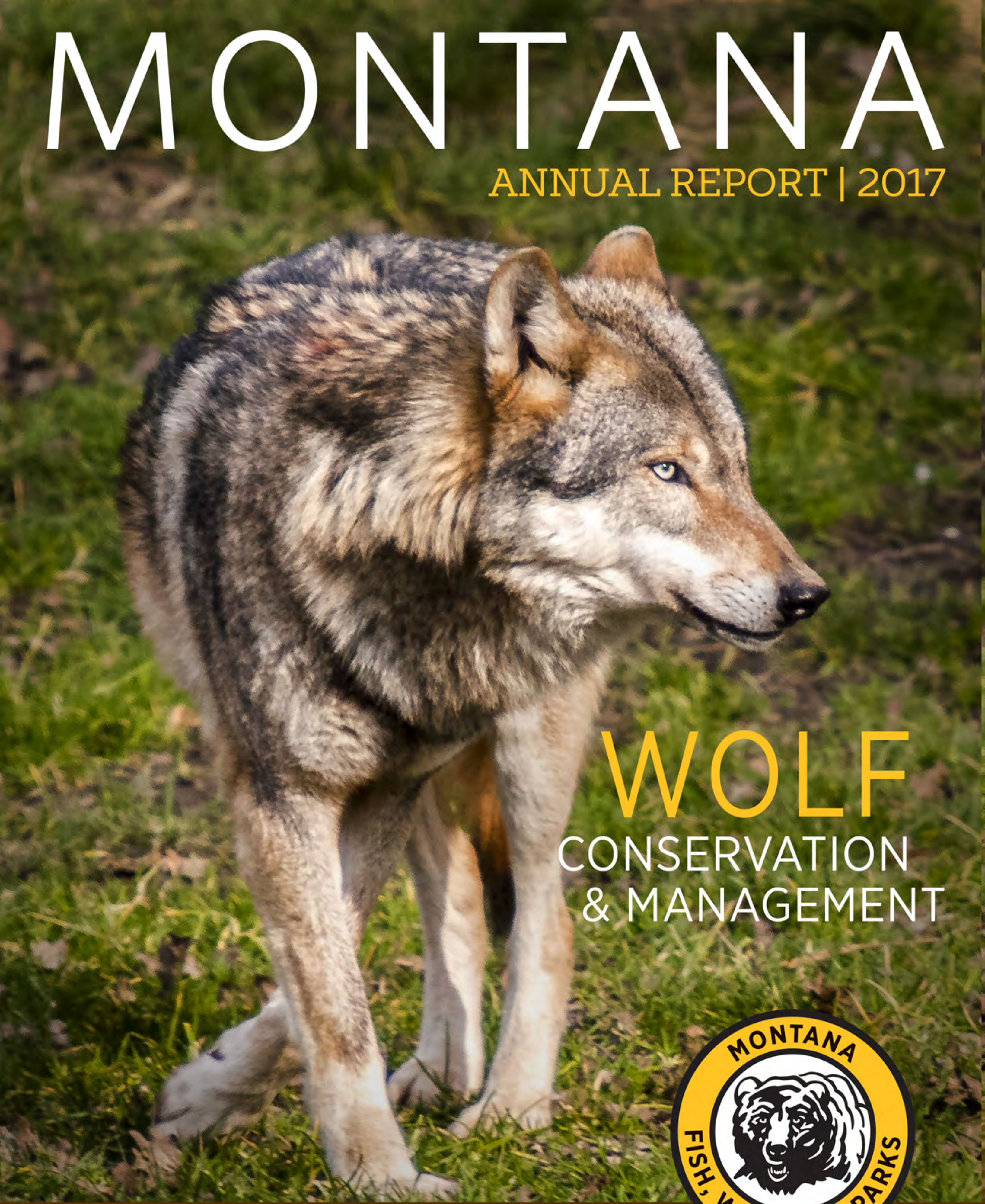
MONTANA

ANNUAL REPORT | 2017



WOLF

CONSERVATION & MANAGEMENT

MONTANA FISH, WILDLIFE & PARKS

This report presents information on the status, distribution, and management of wolves in the State of Montana, from January 1, 2017 to December 31, 2017.

This report is also available at: http://fwp.mt.gov/fishAndWildlife/management/wolf/

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Montana Gray Wolf Program
2017 Annual Report

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EXECUTIVE SUMMARY

Wolf recovery in Montana began in the early 1980's. The federal wolf recovery goal of 30 breeding pairs for 3 consecutive years in the Northern Rocky Mountains (NRM) of Montana, Idaho and Wyoming was met by 2002. Montana's state Wolf Conservation and Management Plan of 2004 was based on the work of a citizen's advisory council and was approved by the United States Fish and Wildlife Service (USFWS). The wolf population in the NRM tripled between the time recovery goals were met and when wolves were ultimately delisted by congressional action during 2011. At present, Montana Fish, Wildlife and Parks (FWP) implements the 2004 state management plan using a combination of sportsman license dollars and federal Pittman-Robertson funds (excise tax on firearms, ammunition, and hunting equipment) to monitor the wolf population, regulate sport harvest, collar packs in livestock areas, coordinate and authorize research, and direct problem wolf control under certain circumstances.

The primary means of monitoring wolf distribution, numbers, and trend in Montana is now "Patch Occupancy Modeling," or "POM." The POM method utilizes annual hunter effort surveys, known wolf locations, habitat covariates, and estimates of wolf territory size and pack size to estimate wolf distribution and population size across the state. POM estimates of wolf population size are the preferred monitoring method due to accuracy, confidence intervals, and cost efficiency. The most recently completed POM estimates for wolf population size were 961 wolves during 2015 and 851 wolves during 2016 (Fig. 1). Data have been gathered for 2017 POM estimates of wolf numbers and distribution, and analysis will take place during summer 2018. FWP is currently working with the University of Montana to refine POM by incorporating contemporary data (after initiation of a wolf hunting and trapping season) on territory and pack sizes derived with improved collar technology.

Wolf hunting was recommended as a management tool in the 2004 Montana Wolf Conservation and Management Plan. Calendar year 2017 included parts of two hunting/trapping seasons for wolves. During calendar year 2017, 65 wolves were harvested during the spring, and 168 wolves were harvested during the fall for a total of 233 (Fig. 1). Sales of license year 2017/18 wolf hunting licenses generated $380,261 for wolf management in Montana.

Wildlife Services (WS) confirmed 80 livestock losses to wolves including 49 cattle, 12 sheep, and 19 goats during 2017 (Fig. 1). One dog was also killed by wolves. This total was up compared to 53 livestock losses during 2016. During 2017 the Montana Livestock Loss Board paid $64,133 for livestock that were confirmed by WS as killed by wolves or probable wolf kills. Fifty-seven wolves were killed to reduce the potential for further depredation. Of the 57 wolves, 42 were killed by WS and 15 were lawfully taken by private citizens. FWP's Wolf Specialists radio-collared 22 wolves during 2017 to meet the legislative requirement for collaring livestock packs and to aid in population monitoring and research efforts.

FWP confirmed the presence of at least 124 packs, 633 wolves, and 63 breeding pairs in Montana at the end of 2017 (Fig. 1, Appendix 4).

Montana's wolf population grew steadily from the early 1980's when there were less than 10 in the state. After wolf numbers approached 1,000 in 2011 and wolves were delisted, the wolf population has decreased slightly and may be stabilizing (Fig. 1). Stabilization and reduced livestock depredation in recent years may be related to the onset of wolf hunting and trapping along with more aggressive depredation control actions. Montana's wolf population remains well-above requirements (5-6x). Wolf license sales have generated $3.4 million for wolf management and monitoring since 2009.

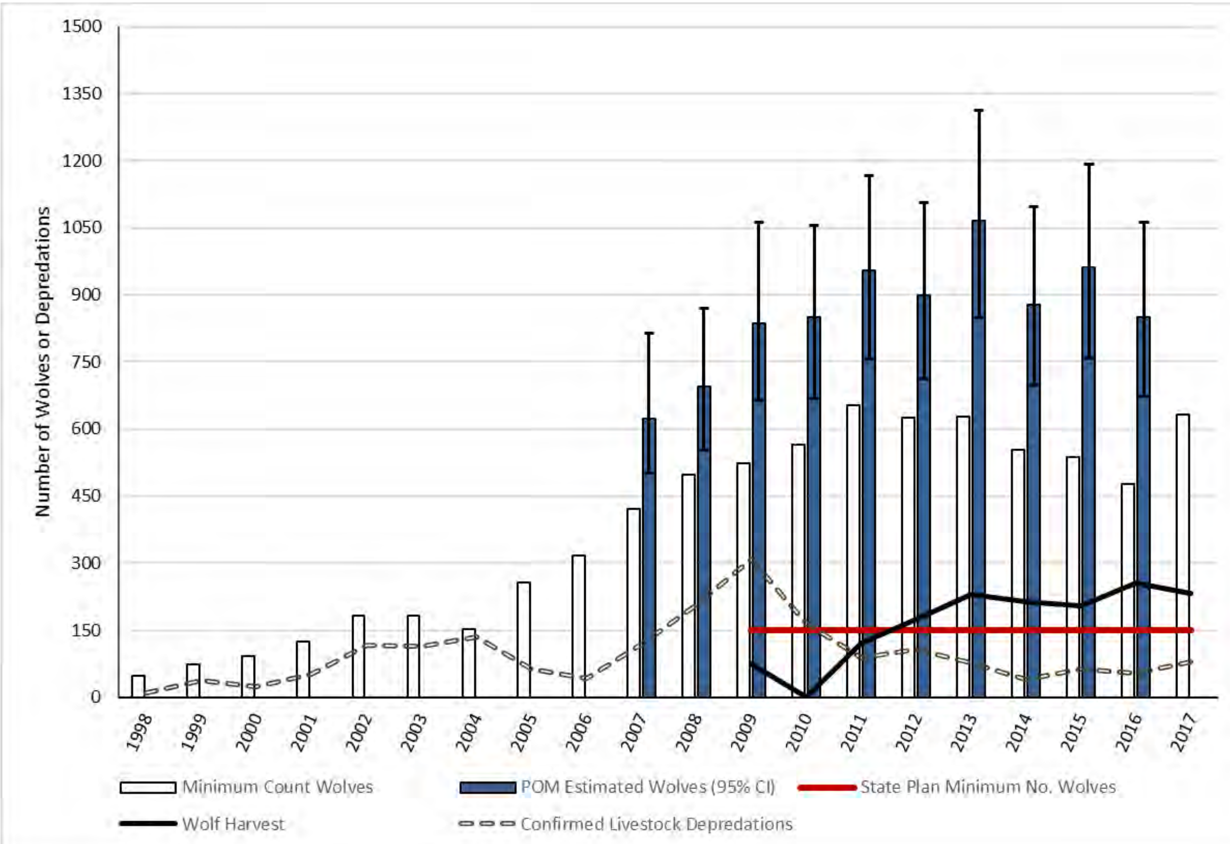


Figure 1. Patch Occupancy Modeling ("POM") estimated number of wolves in Montana (including 95% confidence intervals) and verified minimum number of wolves residing in Montana in relation to state wolf plan requirements along with trends in wolf harvest and confirmed livestock losses due to wolves, 1998 – 2017.

1. BACKGROUND

Wolf recovery in Montana began in the early 1980’s. Wolves increased in number and distribution because of natural emigration from Canada and a successful federal effort that reintroduced wolves into Yellowstone National Park and the wilderness areas of central Idaho. The federal wolf recovery goal of 30 breeding pairs for 3 consecutive years in Montana, Idaho and Wyoming was met during 2002, and wolves were declared to have reached biological recovery by the U.S. Fish and Wildlife Service (USFWS) that year. During 2002 there were a minimum of 663 wolves and 43 breeding pairs in the Northern Rocky Mountains (NRM).

The Montana Gray Wolf Conservation and Management Plan was approved by the USFWS in 2004. Nine years after having been declared recovered and with a minimum wolf population of more than 1,600 wolves and 100 breeding pairs in the NRM, in April 2011, a congressional budget bill directed the Secretary of the Interior to reissue the final delisting rule for NRM wolves. On May 5, 2011 the USFWS published the final delisting rule designating wolves throughout the Designated Population Segment (DPS), except Wyoming, as a delisted species.

Beginning with delisting in May 2011, the wolf was reclassified as a species in need of management in Montana. Montana’s laws, administrative rules, and state plan replaced the federal framework. The Montana Wolf Conservation and Management Plan is based on the work of a citizen’s advisory council. The foundations of the plan are to recognize gray wolves as a native species and a part of Montana’s wildlife heritage, to approach wolf management similar to other wildlife species such as mountain lions, to manage adaptively, and to address and resolve conflicts. As noted in the State Plan, “Long-term persistence of wolves in Montana depends on carefully balancing the complex biological, social, economic, and political aspects of wolf management.”

At present, Montana Fish, Wildlife and Parks (FWP) implements the state management plan using a combination of sportsman license dollars and federal Pittman-Robertson funds (excise tax on firearms, ammunition, and hunting equipment) to monitor the wolf population, regulate sport harvest, coordinate and authorize research, and direct problem wolf control under certain circumstances. Several state statutes also guide FWP’s wolf program. FWP and partners have placed increasing emphasis on proactive prevention of livestock depredation. USDA Wildlife Services (WS) continues to investigate injured and dead livestock, and FWP works closely with them to resolve conflicts. Montana’s Livestock Loss Board compensates producers for losses to wolves and other large carnivores.

Montana wolf conservation and management has transitioned to a more fully integrated program since delisting. With wolf population level securely above requirements for over a decade, FWP continues to adapt the wolf program to match resources and needs. For years, when the population was small and wolves were listed, a “wolf weekly” report was issued, detailing all depredations, collaring, control and known mortalities. That level of detail and its associated expense is no longer warranted, and the information is now reported annually. This allows limited personnel time and conservation dollars to be allocated more effectively.

Population monitoring techniques are also changing. Wolf packs have been intensively monitored year-round beginning with their return to the northwestern part of Montana in the 1980's. Objectives for monitoring during the period of recovery were driven by the USFWS's recovery criteria – 30 breeding pairs for 3 consecutive years in Montana, Idaho, and Wyoming. Similar metrics of population status were used over the last 15 years from the time recovery criteria were met in 2002, through delisting in 2011, and for the 5 years when the USFWS retained oversight after delisting. These population monitoring criteria and methods were appropriate and achievable when the wolf population was small and recovering. For instance, in 1995, when the US Fish and Wildlife Service reintroduced wolves into Yellowstone National Park and central Idaho, the end-of-year count for wolves residing in Montana was 66. In the early years, most wolf packs had radio-collared individuals, and intensive monitoring was possible to identify new packs and most individuals within packs. However, for nearly a decade, the minimum count of wolves has approached or exceeded 500 individuals distributed across more than 25,000 square miles of mostly rugged and remote terrain in western Montana. Therefore, the ability to count every pack, every wolf, and every breeding pair has become expensive, unrealistic, and unnecessary. Consequently, FWP has been exploring other, more cost-effective methods. These methods can be more accurately described as population estimates that account for uncertainty (confidence intervals), as opposed to minimum counts whose end result, at this time, reflects total effort (and dollars spent) as much as population status.

FWP first began considering alternative approaches to monitoring the wolf population in 2006. Preliminary work focused on developing a more reliable and cost-effective method to estimate the number of breeding pairs based on the size of a wolf pack using logistic regression models (Mitchell et al. 2008). Subsequent work focused on finding ways to utilize wolf observations by hunters in a more systematic way. A collaborative research effort with the University of Montana Cooperative Wildlife Research Unit was initiated in 2007. The primary objective was to find an alternative approach to wolf monitoring that would yield statistically reliable estimates of the number of wolves, the number of wolf packs, and the number of breeding pairs (Glenn et al. 2011). Ultimately, a method applicable to a sparsely distributed and elusive carnivore population was developed that used hunter observations as a cost-effective means of gathering biological data to estimate the area occupied by wolves in Montana - "Patch occupancy modelling" (POM).

POM is a modern, scientifically valid, and financially efficient means of monitoring wolves. POM is the best and most efficient method to document wolf population numbers and trend at this point in time. FWP is confident that the wolf population estimate and trend that POM provides is sufficient and scientifically valid evidence that can be used to assess wolf status relative to the criteria outlined in Montana's Wolf Conservation and Management Plan. Minimum counts and pack tables will no longer be reported, beginning with the 2018 annual report. Instead, the more appropriate and efficient techniques that have been in development for a decade will be used. If new and improved techniques become available in the future, those methods may be implemented when appropriate.

For 2017, we continue to include traditional metrics (minimum wolves and breeding pairs). The 2017 POM estimate will be made available by fall 2018 in a supplement to the annual report. The release of the estimate at that time, rather than in this report, is necessary because of the timing of data collection associated with making the POM estimate. The data (wolf observations) are collected during spring phone surveys, and analysis occurs during summer. The date of the annual wolf report will also shift to later in the year so that the POM estimate for the year can be included in that year's annual report. The time period covered will also shift; this and previous reports have covered a calendar year. This was due to the Dec. 31 minimum count and breeding pair metrics. Future reports will shift to reflect a biological year (BY), or May 1 – April 30. Most wolves have been born by May 1, and most annual mortality, including completion of hunting and trapping seasons, has also occurred by that date.

2. WOLF POPULATION MONITORING

2.1 Wolf Distribution and Numbers

We used patch occupancy modelling to estimate the distribution and number of wolves in Montana. The general method was to 1) estimate the area occupied by wolves in packs, 2) estimate the numbers of wolf packs by dividing area occupied by average territory size and correcting for overlapping territories, and 3) estimate the numbers of wolves by multiplying the number of estimated packs by average annual pack size and accounting for lone wolves (Fig. 2).

Patch Occupancy Modelling Methods
To estimate the area occupied by wolf packs from 2007 to 2016, we used a multi-season false-positives occupancy model (Miller et al. 2013) using program PRESENCE (Hines 2006). First, we created an observation grid for Montana (Fig. 2A) with a cell size large enough to ensure observations of packs across sample periods, yet small enough to minimize the occurrences of multiple packs in the same cell on average (cell size = 600 km^2). We used locations of wolves in packs (2-25 wolves) reported by a random sample of unique deer and elk hunters during FWP annual Hunter Harvest Surveys (Fig. 2B) and assigned the locations to cells (Fig. 2C). We modeled detection probability, initial occupancy, and local colonization and local extinction from 5, 1-week encounter periods along with verified locations (Fig. 2D) using covariates that were summarized at the grid level (Fig. 2E). Verified wolf pack locations (centroids), were used to estimate probabilities of false detection. We estimated patch-specific estimates of occupancy (Fig. 2F) and estimated the total area occupied by wolf packs by multiplying patch-specific estimates of occupancy by their respective patch size and then summing these values across all patches (Fig. 2G). Our final estimates of the total area occupied by wolf packs were adjusted for partial cells on the border of Montana and included model projections for reservations and national parks where no hunter survey data were available.

Model covariates for detection included hunter days per km^2 by hunting district per year (an index to spatial effort), proportion of wolf observations that were mapped (an correction for effort), low use forested and non-forested road densities (indices of spatial accessibility), a spatial autocovariate (the proportion of neighboring cells with wolves seen out to a mean dispersal distance of 100 km), and patch area sampled (because smaller cells on the border of Montana, parks, and Indian Reservations have less hunting activity and therefore less opportunity for hunters to see wolves). Model covariates for occupancy, colonization, and local extinction included a principal component constructed from several autocorrelated environmental covariates (percent forest cover, slope, elevation, latitude, percent low use forest roads, and human population density), and recency (the number of years with verified pack locations in the previous 5 years).

To estimate area occupied in each year, we calculated unconditional estimates of occupancy probabilities which provided probabilities for sites that were not sampled by Montana hunters (such as National Parks and Reservations). We accounted for uncertainty in occupancy

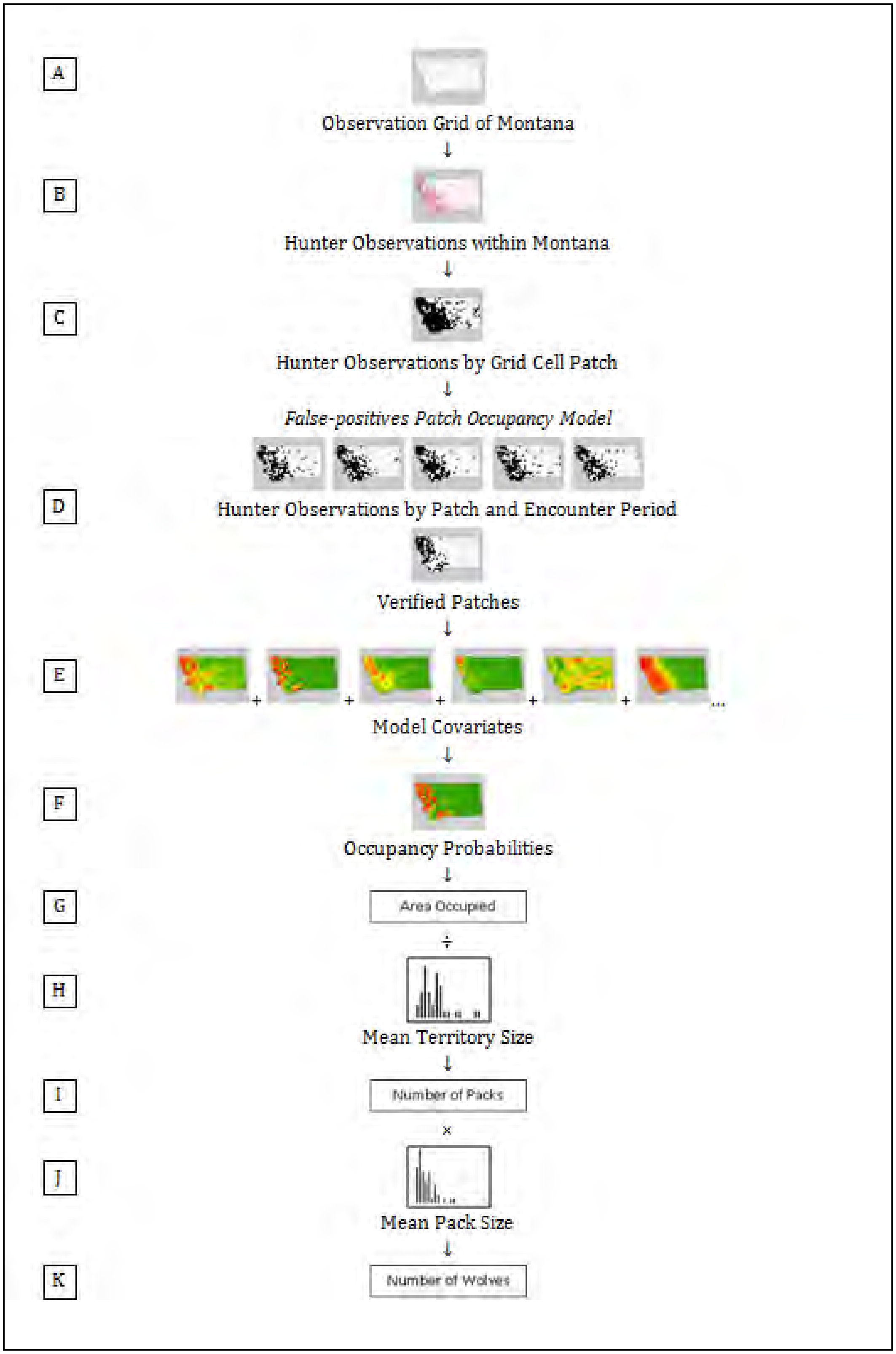


Figure 2. Schematic for method of estimating the area occupied by wolves, number of wolf packs and number of wolves in Montana, 2007-2016.

estimates using a parametric bootstrap procedure on logit distributions of occupancy probabilities. For each set of bootstrapped estimates we calculated area occupied. The 95% confidence intervals (C.I.s) for these values were obtained from the distribution of estimates calculated from the bootstrapping procedure.

To predict the total number of wolf packs in Montana from 2007 to 2016 we first established an average territory size for wolf packs in Montana (Fig. 2H). Rich et al. (2012) calculated 90% kernel home ranges from radio telemetry locations of wolves collared and tracked by FWP wolf biologists for research and/or management from 2008 to 2009. We assumed the mean estimate of territory size from these data was constant during 2007-2016. For each year, we estimated the number of wolf packs by dividing our estimates of total area occupied by the mean territory size (Fig. 2I). We then accounted for annual changes in the proportion of territories that were overlapping (non-exclusive) using the number of observed cells occupied by verified pack centers. We accounted for uncertainty in territory areas using a parametric bootstrap procedure and a log-normal distribution of territory sizes, and for each set of bootstrapped estimates we calculated mean territory size. The 95% C.I.s for these values were obtained from the distribution of estimates calculated from the bootstrapping procedure.

To predict the total number of wolves in Montana from 2007 to 2016, we first calculated average pack size from the distribution of packs of known size (Fig. 2J). Pack sizes were established by FWP biologists for packs monitored for research and/or management. We used end-of-year pack counts for wolves documented in Montana from 2007 to 2016; we only used pack counts FWP biologists considered complete, i.e., good/moderate counts. Typically, intensively monitored packs with radio-collars provided complete counts more often than packs that were not radio-marked. For each year, we estimated total numbers of wolves in packs by multiplying the estimate of mean pack size by the annual predictions of number of packs (Fig. 2K). We accounted for uncertainty in pack sizes using a parametric bootstrap procedure and a Poisson distribution of pack sizes, and for each set of bootstrapped estimates we calculated mean pack size. The 95% C.I.s for these values were obtained from the distribution of estimates calculated from the bootstrapping procedure. We allowed pack sizes to vary by year but not spatially.

Finally, our population estimate is for wolves in groups of 2 or more factored in lone or dispersing wolves into the population estimate by adding 12.5%. Various studies have documented that on average 10-15% of wolf populations are composed of lone or dispersing wolves (Fuller et al. 2003). The state of Idaho adds 12.5% to account for lone wolves (Idaho Department of Fish and Game and Nez Perce Tribe 2012) and Minnesota adds 15% (Erb 2008).

Area Occupied by Wolves in Packs

From 2007 to 2016, between 50,039 and 82,387 hunters responded annually to the wolf sighting surveys. From their reported sightings, 1,064 to 3,469 locations of 2 to 25 wolves were determined each year during the 5, 1-week sampling periods. Percent of hunters reporting a wolf sighting ranged from 1.8% (2016) to 4.2% (2010).

The top model of wolf occupancy showed positive associations between the initial probability that wolves occupied an area and an environmental principal component and recency. The probability that an unoccupied patch became occupied in subsequent years was positively related to an environmental principal component and recency. The probability that an occupied patch became unoccupied in the following year was negatively associated with an environmental principal component. The probability that wolves were detected by a hunter during a 1-week sampling occasion was positively related to hunter days per hunting district per year, low use forest road density, low use non-forest road density, a spatial autocovariate, the proportion of observations mapped, and area sampled. The probability that wolves were falsely detected by a hunter during a 1-week sampling occasion was positively related to hunter days per hunting district per year, low use forest road density, low use non-forest road density, and a spatial autocovariate

From 2007 to 2016, estimated area occupied by wolf packs in Montana ranged from 42,098 km^2 (95% CI = 42,096 to 44,881) in 2007 to 76,215 km^2 (95% CI = 75,952 to 76,865) in 2012 (Table 1). The predicted distribution of wolves from the occupancy model closely matched the distribution of field-confirmed wolf locations (verified pack locations and harvested wolves; Fig. 3). Although the estimated area occupied has nearly doubled between 2007 and 2016, the rate of growth for the area occupied has been declining. The extent to which this declining rate of increase represents a population responding to density dependent factors as available habitats become filled, versus a response to hunting and trapping harvest, is unknown.

Number of Wolf Packs

In 2008 and 2009, territory sizes from 38 monitored packs ranged from 104.70 km^2 to 1771.24 km^2. Mean territory size was 599.83 km^2 (95% C.I. = 478.81 to 720.86; Rich et al. 2012). Dividing the estimated area occupied by mean territory size resulted in an estimated number of packs that ranged from 70 (95% C.I. = 59 to 88) in 2007 to 127 (95% C.I. = 103 to 155) in 2012 (Table 1). We adjusted these estimates to account for annual changes in the number of verified pack centers per grid from 2007 to 2016 (1.12, 1.08, 1.13, 1.16, 1.26, 1.27, 1.33, 1.24, 1.26, and 1.32 for each respective year during 2007-2016) as an index of territory overlap. Accounting for territory overlap, estimated numbers of packs ranged from 79 (95% C.I. = 66 to 99) in 2007 to 167 (95% C.I. = 136 to 204) in 2013 (Table 1).

Our estimate for total numbers of wolf packs exceeded the minimum count by 7 to 21% between 2007 and 2016. Such a level of undercount is not unreasonable for elusive carnivores and is within the range of imperfect detection recorded for many other wildlife species and population estimation methods. For example, detection rates of elk during aerial surveys can be less than 20% (e.g., Vander Wal et al 2011), and detection rates of elk during winter surveys on the open winter ranges in southwestern Montana have been estimated at 44-89% (Hamlin and Ross 2002). The estimated number of packs exceeded the minimum number of verified packs to some degree because verified packs did not include border packs, and some wolf mortality occurred between the 5-week sampling period and end of year counts.

Table 1. Estimated area occupied by wolves, number of wolf packs, and number of wolves in Montana, 2007-2016. Annual numbers were based on best available information and were retroactively updated as new information was obtained.

Year	Area Occupied[1]	Territory Size[2]	Packs[3]	Pack Size[4]	Wolves[5]	95% CI
2007	42,098	600	79	7.0	623	501-815
2008	51,702	600	93	6.7	694	553-870
2009	61,730	600	117	6.4	836	663-1,063
2010	63,283	600	123	6.2	849	667-1,055
2011	70,629	600	149	5.7	955	757-1,166
2012	76,215	600	161	5.0	899	713-1,105
2013	75,219	600	167	5.7	1,065	849-1,313
2014	70,022	600	145	5.4	878	698-1,098
2015	72,508	600	152	5.6	961	759-1,193
2016	69,092	600	152	5.0	851	673-1,062

[1] Area of Montana occupied by wolf packs (km^2)

[2] Average Montana wolf territory size (km^2) from Rich et al. 2012

[3] 600 km^2 territories with overlap based on

[4] Average pack size from complete counts

[5] Estimated number of wolves including lone wolves (95% Confidence Interval)

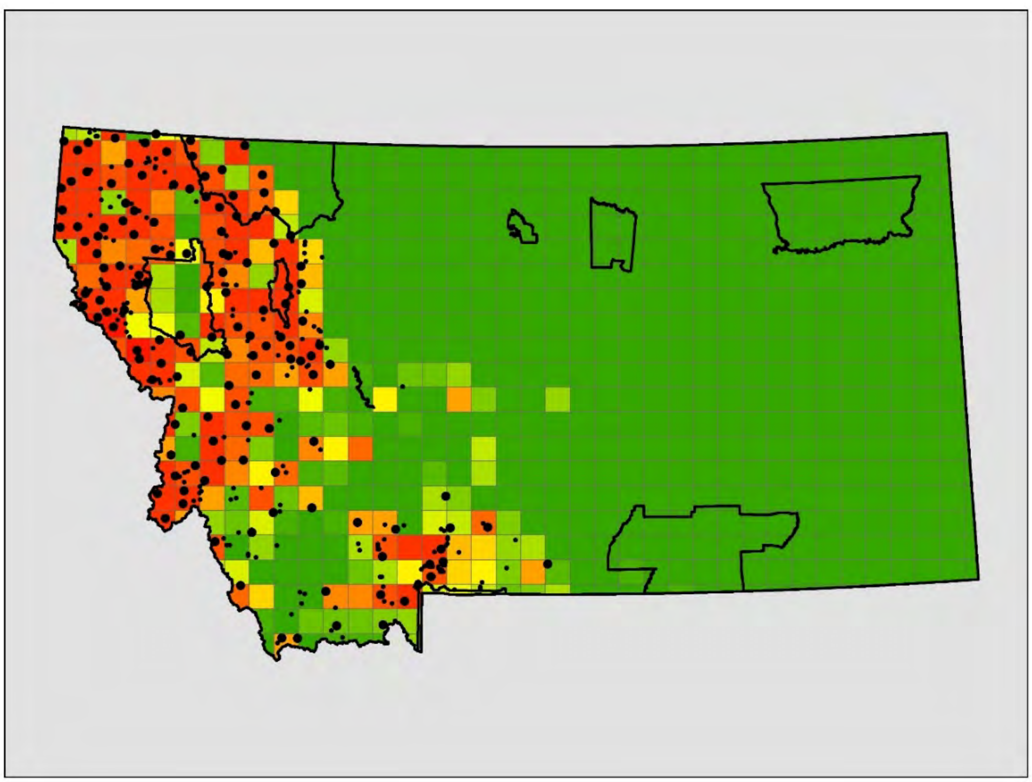


Figure 3. Model predicted probabilities of occupancy (ranging from low to high [green to red]), verified pack centers (large dots), and harvest locations (small dots) in Montana, 2016.

Our estimate of the number of wolf packs assumes that territory size is constant and equal across space. If territory sizes were actually larger in some years or some areas, then the estimated number of packs in those years or areas would have been biased high, and if territory sizes were actually smaller in some years or some areas, then the pack estimates would have been biased low in those years or areas. Similarly, our estimates of territory overlap were indirect indices rather than field-based observations based on high-quality telemetry data. In future applications of this technique, the assumption of constant territory sizes could be improved by modeling territory size as a flexible parameter, incorporating estimates of inter-pack buffer space or territory overlap into estimates of exclusive territory size, and incorporating spatially and temporally variable territory size predictions into estimates of pack numbers.

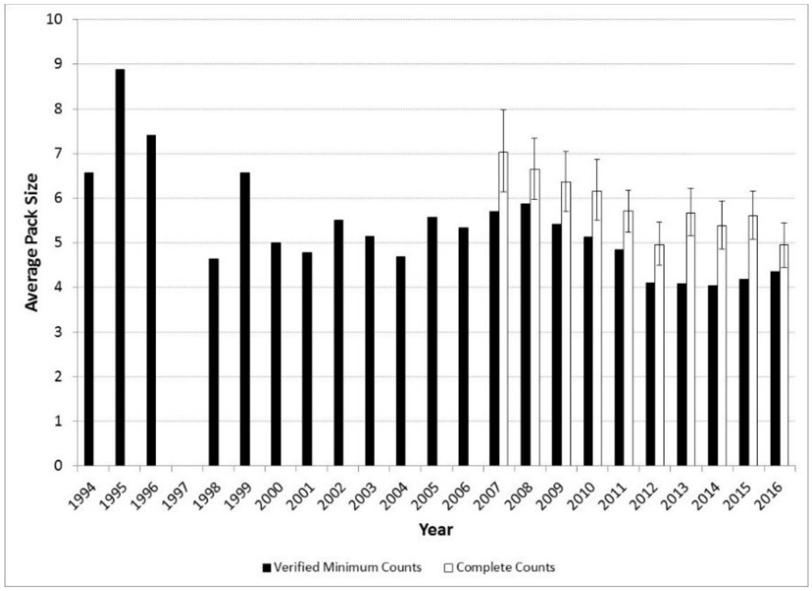
Number of Wolves

From 2007 to 2016, complete counts (classified as good or moderate quality) were obtained from 664 packs within Montana. Pack sizes ranged from 2 to 22 and mean pack sizes ranged from 7.03 (95% C.I. = 6.15 to 7.97) in 2007 to 4.96 (95% C.I. = 4.44 to 5.44) in 2016 (Table 1). Pack sizes for complete counts ranged from 13% larger than for minimum verified counts in 2008 to 39% larger in 2013 (Fig. 4). Multiplying estimated packs by mean pack size and a multiplication factor of 1.125 to account for the percentage of the population presumed to be lone wolves (Mech and Boitani 2003, p. 170) resulted in a low of wolves at 623 in 2007 to a high of wolves at 1,065 in 2013 (Table 1). The estimated number of wolves ranged from 40% larger than the minimum verified number of wolves in Montana in 2008 to 78% larger in 2016 (Fig. 5).

Our estimate of the number of wolves is dependent on several assumptions. First, our population estimate assumes that missed packs are the same size as verified packs. If missed packs are smaller (e.g., recently established packs or packs interspersed among known packs), then our estimated number of wolves would be biased high. Also, our estimate assumes that pack size is constant and equal across space. Pack sizes that were actually larger in some years or some areas would lead to underestimation of wolf numbers, and pack sizes that were smaller in some years or areas would lead to an overestimation of wolf numbers. As with packs, the estimated number of wolves exceeded the minimum number of verified wolves to some degree because verified wolves did not include individuals associated with border packs and the timing of the estimates are slightly different.

Future applications of this modeling and population estimation technique will include incorporation of harvest (locations and number of harvested wolves) effects on wolf occupancy, territory sizes and overlap, and pack sizes. Incorporation of harvest as a model covariate for each of these aspects of wolf population size will enable a formal assessment of the effects of harvest on wolf populations in Montana. This strategy will also allow for predictions of the effects of different seasons or harvest quotas on wolf populations, to provide information to decision makers as they set wolf hunting and trapping seasons in coming years. Therefore, in addition to its use for monitoring and wolf population estimation, the technique described here also will provide utility for directly informing decisions about public harvest of wolves.

Figure 4. Mean number of wolves per pack with complete counts in Montana compared to the mean number of wolves per pack with verified minimum counts in Montana, 2007-2016. Annual numbers were based on best available information and were retroactively updated as new information was obtained.



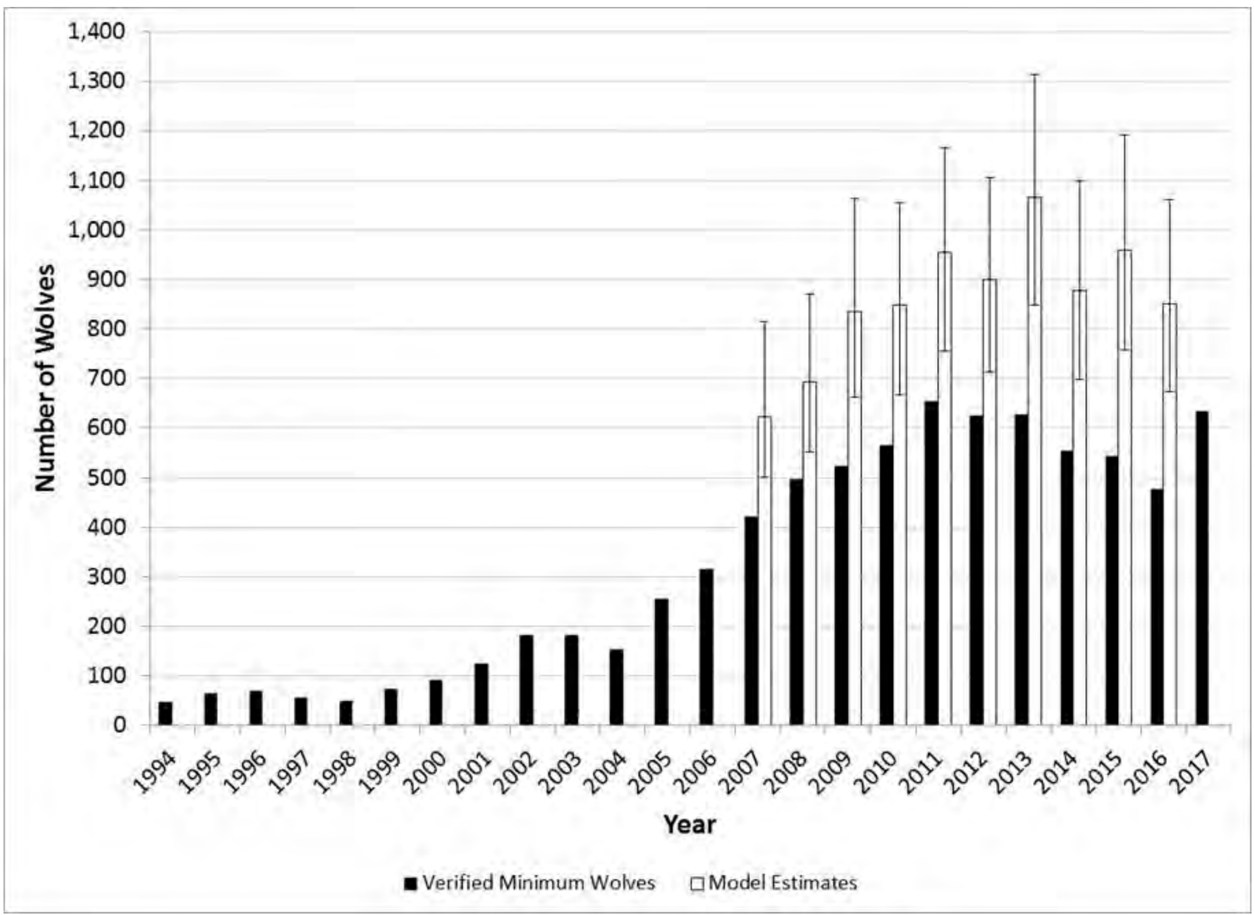


Figure 5. Estimated number of wolves in Montana compared to the verified minimum number of wolves residing in Montana, 2007-2016. Annual numbers were based on best available information and were retroactively updated as new information was obtained.

2.2 Wolf Recruitment

Breeding pairs has been a traditional metric used for wolf recovery. The purpose of including breeding pairs as a population metric during wolf recovery was to ensure that reproduction and survival of young was occurring so that the population could continue to grow in size and expand. Montana was required by the USFWS to have a minimum of 15 breeding pairs defined as two adults and two pups surviving until December 31 to meet wolf recovery goals. Montana's state wolf plan has similar metrics – a minimum of 15 packs/breeding pairs. A minimum count of known breeding pairs has been a part of annual wolf reports for many years. However, the USFWS's 2009 delisting rule and the Montana state plan both recognized the importance of allowing flexibility in population monitoring approaches so that new, more efficient and effective techniques could be implemented in the future.

Meeting the threshold of 15 breeding pairs requires a minimum of 30 individuals to be recruited into the population. We estimated wolf recruitment in Montana for 2008-2016 by calculating the difference in POM population size in years A and B (consecutive years) after subtracting known wolf mortalities from the first year (A). For instance, if the population was estimated via POM to be 500 wolves in 2000, and 600 wolves in 2001, and there were 100 known wolf mortalities from all sources in 2000, the number of wolves recruited from 2000 to 2001 would be 200. The population was 500 in year A; 100 wolves were known to have died in year A, which leaves 400; and the population was 600 in year B, which means 200 wolves were recruited into the population.

Since 2008, Montana has exceeded the recruitment metric by 493 – 1,633% (Table 2). These numbers are minimum estimates due to the fact that natural mortalities also occur and go undocumented. Unaccounted natural mortality would lower the number of wolves in year A even further, requiring even more recruitment to achieve the population size in year B.

Table 2. Minimum wolf recruitment estimated with annual Patch Occupancy Modelling (POM) population size and all known wolf mortalities in Montana, 2008-2016.

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Wolf Population Estimate (POM)	623	694	836	849	955	899	1065	878	961	851	.
Total Annual Known Wolf Mortalities	100	160	240	178	216	324	335	308	276	334	305
Minimum Recruitment		171	302	253	284	160	490	148	391	166	.
Percent of Minimum Required (30)		570%	1007%	843%	947%	533%	1633%	493%	1303%	553%	

2.3 Minimum Counts of Wolves and Breeding Pairs

Methods for Counting Minimum Number of Packs, Individuals, and Breeding Pairs

The total number of wolf packs is determined by counting the number of animal groups with 2 or more individuals holding a territory that existed on the Montana landscape on December 31. If a pack was removed because of livestock conflicts or otherwise did not exist at the end of the calendar year, it is not included in the year-end total. Border packs are counted only if they denned or spent the majority of their time in Montana. We account for all known wolf mortality by assigning harvest and all other known mortalities to a pack or lone wolf, and these mortalities are subtracted from known pack sizes to derive the minimum estimated pack sizes and minimum count of wolves for the year. Packs of 2 or more adult wolves that meet the 1994 definition of "an adult male and a female wolf that have produced at least 2 pups that survived until December 31." are counted as "breeding pairs" (Appendix 3). Breeding pair status for every known pack in Montana cannot be verified with existing personnel and funding. Thus, the count of breeding pairs is also a minimum.

2017 Minimum Count of Wolves and Breeding Pairs

As indicated by this and other methods above, the Montana wolf population is far above the 150 wolf and 15 breeding pair minimums of the state plan, as it has been for over a decade. At December 31, 2017, the minimum number of verified packs statewide was 124, the minimum number of wolves was 633, and there were at least 63 breeding pairs (Appendix 3, Fig. 6). As noted previously, these numbers represent minimum counts, and do not necessarily reflect increases or decreases in population when compared to minimum counts of previous years. This is due to variable levels of effort to count wolves each year along with the inability to document all packs, wolves and breeding pairs on the landscape at this point in time.

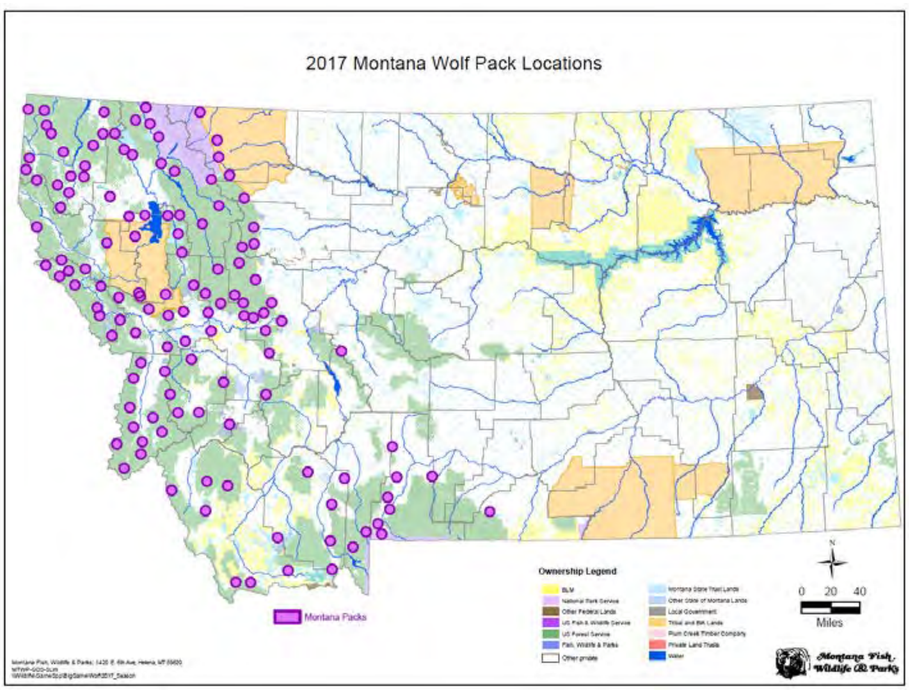


Figure 6. Verified wolf pack distribution in the State of Montana, as of December 31, 2017.

3. WOLF MANAGEMENT

3.1 Regulated Public Hunting and Trapping

Regulated public harvest of wolves was recommended by the Governor's Wolf Advisory Council and included in Montana's Wolf Conservation and Management Plan that was approved by the USFWS during 2004. FWP has developed and implemented wolf harvest strategies that maintain a recovered and connected wolf population, minimize wolf-livestock conflicts, reduce wolf impacts on low or declining ungulate populations and ungulate hunting opportunities, and effectively communicate to all parties the relevance and credibility of the harvest while acknowledging the diversity of values among those parties. The Montana public has the opportunity for continuous and iterative input into specific decisions about wolf harvest throughout the public season-setting process. During 2017 the FWP Commission adopted the framework for the 2017-18 wolf season. There were no proposed changes other than the timing of future wolf season-setting dates. In the past, wolf seasons were on the FWP Wildlife Commission's agenda every year during April (proposals) and June (finals). In the future, wolf seasons will be visited every other year during December (proposals) and February (finals). This timing will allow discussion of ungulate and wolf seasons during the same Commission meeting.

At the close of the 2017-18 wolf season on March 15, 2018, the harvest included 166 taken by hunters and 89 taken by trappers, for a total of 255 wolves harvested during the 2017-2018 season (Fig. 7). The total calendar-year 2017 wolf harvest in Montana was 233, including 65 wolves harvested during spring of the 2016-17 season and 168 wolves harvested during fall of the 2017-18 season. Sales of 2017-18 wolf licenses generated $380,000 for wolf management and monitoring in Montana (Fig. 8).

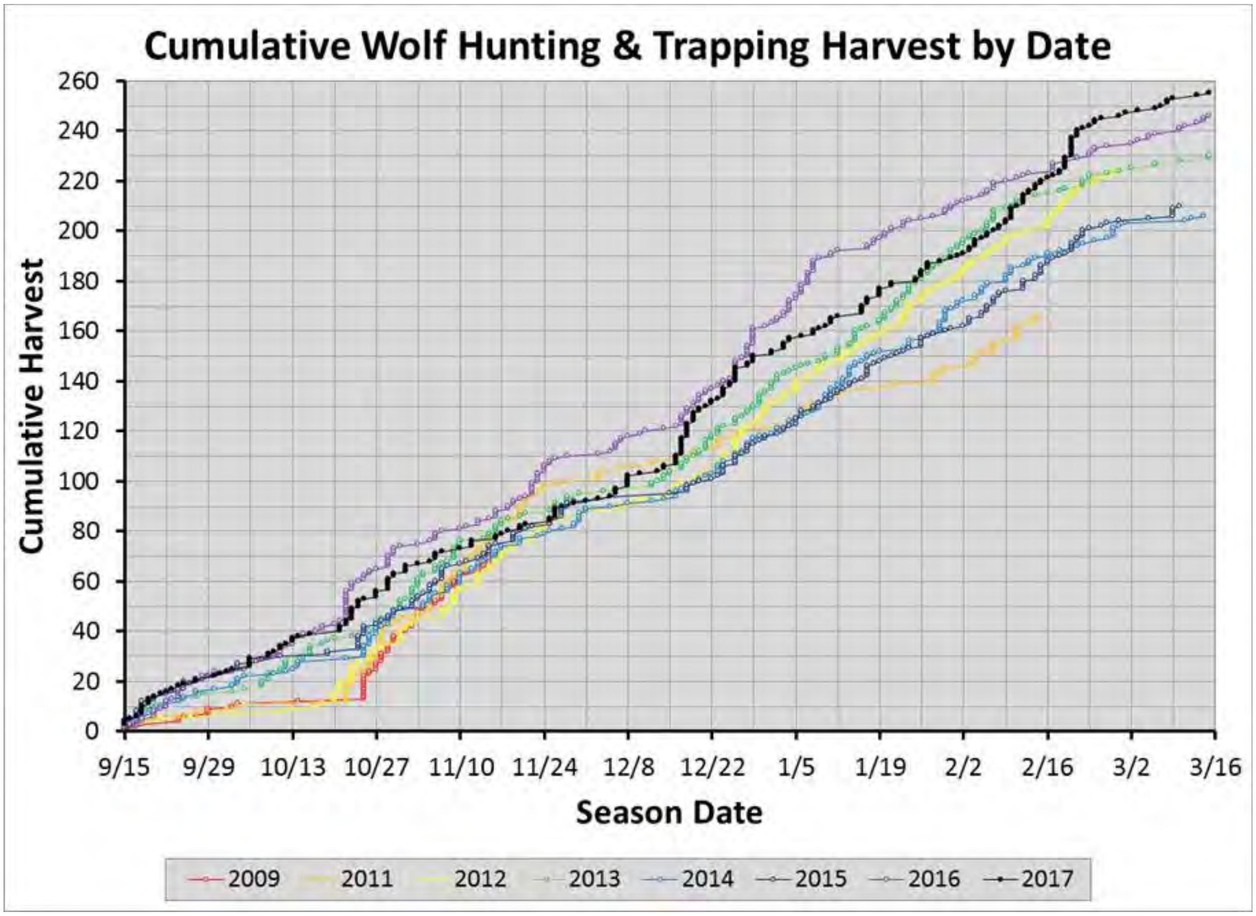


Figure 7. Cumulative wolf hunting and trapping harvest by date, 2009 – 2016.

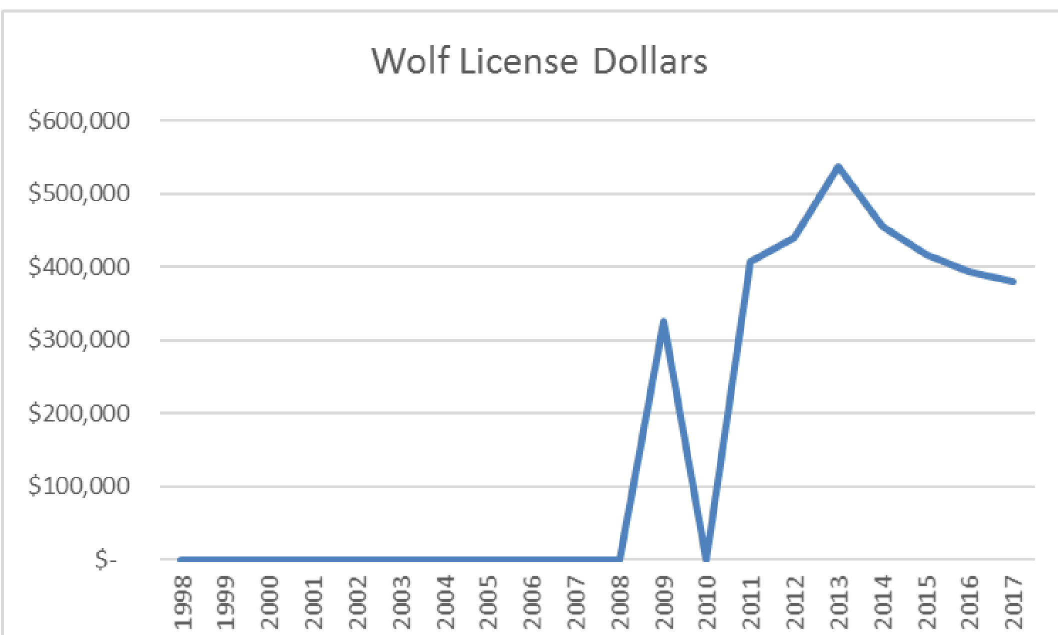


Figure 8. Dollars generated for wolf conservation and management through sales of wolf hunting and trapping licenses in Montana, 1998-2017.

3.2 Wolf – Livestock Interactions in Montana

Montana wolves routinely encounter livestock on both private land and public grazing allotments. Wolves are opportunistic predators, most often seeking wild prey. However, some wolves learn to prey on livestock and teach this behavior to other wolves. The majority of cattle and sheep wolf depredation incidents confirmed by USDA Wildlife Services (WS) occur on private lands. The likelihood of detecting injured or dead livestock is probably higher on private lands where there is greater human presence than on remote public land grazing allotments. The magnitude of under-detection of loss on public allotments is unknown. Most cattle depredations occur during the spring or fall months while sheep depredations occur more sporadically throughout the year.

Wildlife Service's workload increased through 2009 as the wolf population increased and distribution expanded (Fig. 9). The number of complaints received since those years has declined from 233 complaints in FFY 2009 to approximately 100 or less from FFY14-FFY17. About 50% of the complaints received by WS are verified as wolf-caused. Federal and state regulations since 2009 have allowed private citizens to kill wolves seen in the act of attacking, killing, or threatening to kill livestock. From 2009-2016 an average of 10.7 wolves were taken by private citizens. The remainder of wolves killed in control situations were removed by federal agency personnel (Fig. 10).

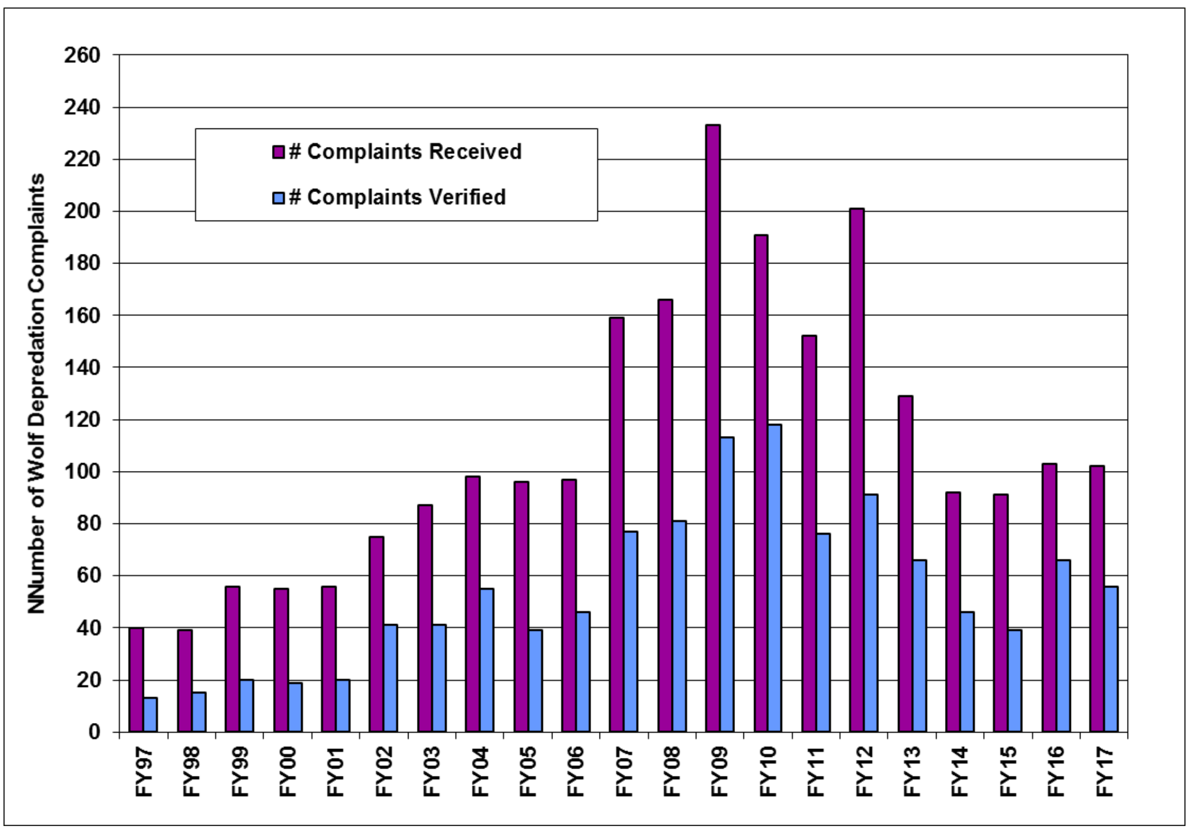


Figure 9. Number of complaints received by USDA Wildlife Services as suspected wolf damage and number of complaints verified as wolf damage, Federal Fiscal Year 1997-2016.

Depredation Incidents during 2017

Wildlife Services confirmed that, statewide, 49 cattle and 12 sheep, 1 dog, and 18 goats were killed by wolves during 2017. Total confirmed cattle and sheep losses were similar to 2013-2016 numbers (Fig. 10). Many livestock producers reported "missing" livestock and suspected wolf predation. Others reported indirect losses including poor weight gain and reduced productivity of livestock. There is no doubt that there are undocumented losses.

To address livestock conflicts and to reduce the potential for further depredations, 57 wolves were killed during 2016, compared to 61 wolves killed during 2016. Forty-two wolves were removed in control actions by USDA Wildlife Services. Fifteen of the 57 wolves were killed by private citizens when wolves were seen chasing, killing, or threatening to kill livestock. Twenty-two packs that existed at some point during 2017 were confirmed to have killed livestock. The general decrease in livestock depredations since 2009 (Fig. 10) may be a result of several factors, primarily more aggressive wolf control in response to depredations (DeCesare et al. 2018).

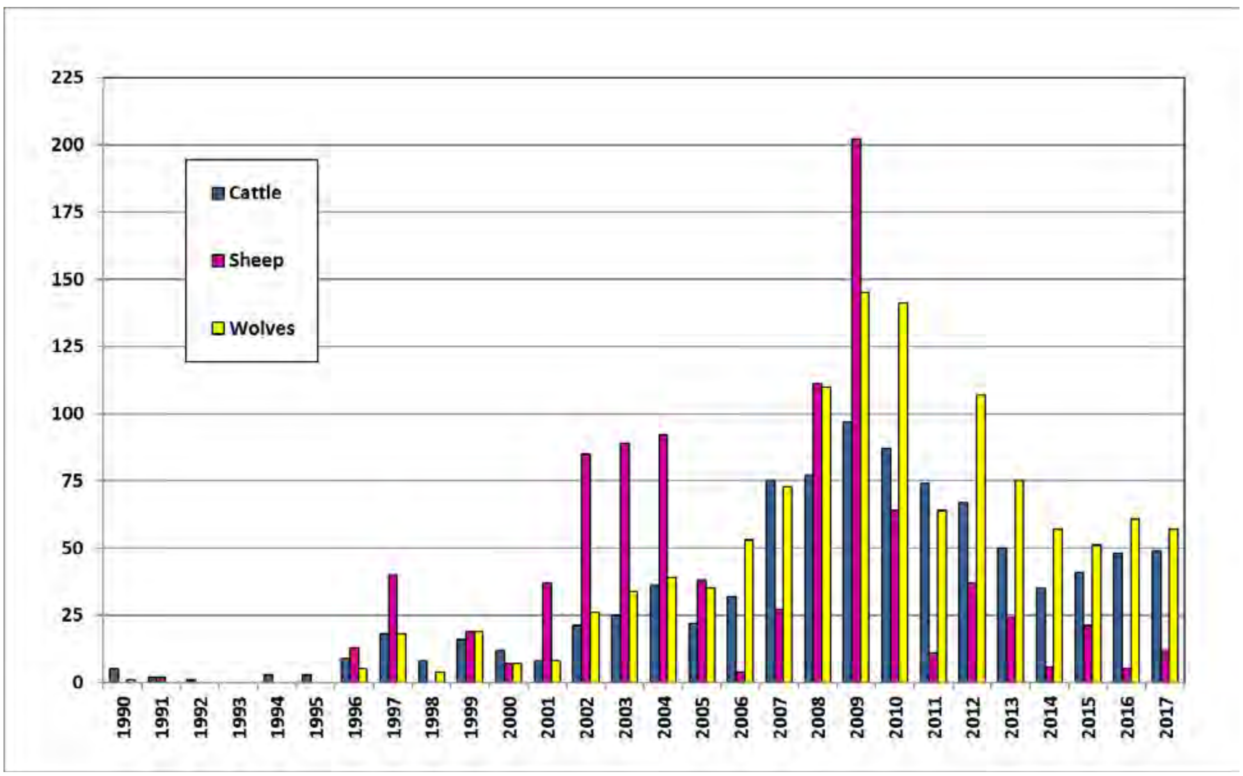


Figure 10. Number of cattle and sheep killed by wolves and number of wolves removed through agency control and take by private citizens, 2000-2016.

Montana Livestock Loss Board Payments
The Montana Wolf Conservation and Management Plan called for creation of this Montana-based program to address the economic impacts of verified wolf-caused livestock losses. The plan identified the need for an entity independent from FWP to administer the program. The purposes of the MLLB are 1) to provide financial reimbursements to producers for losses caused by wolves based on the program criteria, and 2) to proactively apply prevention tools and incentives to decrease the risk of wolf-caused losses and minimize the number of livestock killed by wolves through proactive livestock management strategies. The Loss Mitigation element implements a reimbursement payment system for confirmed and probable losses that are verified by USDA Wildlife Services. Indirect losses and costs are not directly covered. Eligible livestock losses are cattle, calves, hogs, pigs, horses, mules, sheep, lambs, goats, llamas, and guarding animals. Confirmed and probable death losses are reimbursed at 100% of fair market value. Veterinary bills for injured livestock that are confirmed due to wolves may be covered up to 100% of fair market value of the animal when funding becomes available.

Reimbursement totals for 2017 wolf depredations are $64,133 paid to livestock owners on 67 head of livestock. These numbers differ slightly from the WS confirmed losses due to wolves because reimbursements are also made for probable wolf depredations. By comparison, confirmed and probable losses totaled $134,661 from grizzly bears and $10,954 from mountain lions during 2017.

FWP Collaring of Livestock Packs
State Statute 87-1-623 requires Montana Fish, Wildlife and Parks to allocate wolf license dollars toward collaring wolf packs in livestock areas. The purpose of these efforts is to be able to more readily understand which wolf pack may have been involved in a livestock depredation and so that USDA Wildlife Services can be more efficient and effective at controlling packs that depredate on livestock. FWP employs six wolf specialists located in Regions 1, 2, 3, 4, and 5 (Appendix 1) along with seasonal technicians in Regions 1 and 2. Wolf specialists and technicians capture wolves and deploy collars during winter helicopter capture efforts and summer/fall trapping efforts. During 2017, FWP wolf specialists captured and collared 22 wolves (Table 3). Winter conditions were not very favorable during the period when the helicopter was available, and 8 wolves were captured via helicopter darting during January and February 2017. Fourteen wolves were captured and collared by trapping efforts during summer and fall of 2017. USDA Wildlife Services also captured and collared an additional 9 wolves.

Table 3. Wolves captured and radio-collared by FWP Wolf Specialists during 2017.

	Helicopter	Summer/Fall	**Total**
Region 1	2	2	**4**
Region 2	1	5	**6**
Region 3	5	4	**9**
Region 4	0	3	**3**
Total	**8**	**14**	**22**

Proactive Prevention of Wolf Depredation

A range rider program was initiated on private land and USFS grazing allotments west of Augusta in 2017. The program involved two livestock producers and funding from the Livestock Loss Board along with several NGOs. The program was coordinated by Kyran Kunkel through the Mountain Thinking Conservation Collaborative. Additional funding has been secured to continue and expand range rider efforts in the Augusta area for 2018.

FWP collaborated on a wolf conflict prevention program with the Tom Miner Basin Association during 2017. This was the fourth year employing conflict prevention techniques in the area, and none of the cattle herds that were actively managed experienced depredations. These management strategies included altering stocking density, range riding, fladry, and carcass and bone pile management.

In Northwest Montana, FWP was involved in a collaborative proactive risk management project in the Blackfoot Valley. The Blackfoot Challenge Range Rider Project employed seasonal range riders to monitor livestock and predators in areas occupied by the Arrastra Creek, Chamberlain, Morrell Mountain, Inez, Union Peak wolf packs.

FWP was involved in two collaborative, proactive risk management projects in the Big Hole Valley. The first of these projects, a range rider project in the upper Big Hole near Jackson, completed its seventh season in 2017. This project will continue into 2018 with the possibility of adding a second rider in another area of the Big Hole. The second project was a carcass pickup and composting program that was in its third year of operation and will continue in 2018. Guard dogs are still being utilized in the Big Hole, but FWP is not directly active in this project at this time.

Additional work on depredation prevention is described in Appendix 3 - Research, Field Studies, and Project Publications.

3.3 Total 2015 Documented Statewide Wolf Mortalities

FWP detected a total of 305 wolf mortalities during 2017 statewide due to all causes (Fig. 11). Undoubtedly, additional mortalities occurred but were not detected. Documented total wolf mortality in 2017 was 6% lower than 5-year average since 2012. The majority of the decrease was due to lower levels of agency control. Control actions were lower than in 2016, and approximately one-third of peak years. Of the 57 wolves removed in 2017 for livestock depredations, 42 were removed by WS and 15 were legally killed by private citizens under the Montana state laws known as the Defense of Property statute or Senate Bill 200. One wolf was documented as being killed illegally, and 8 wolves were documented as being killed by vehicle or train collision.

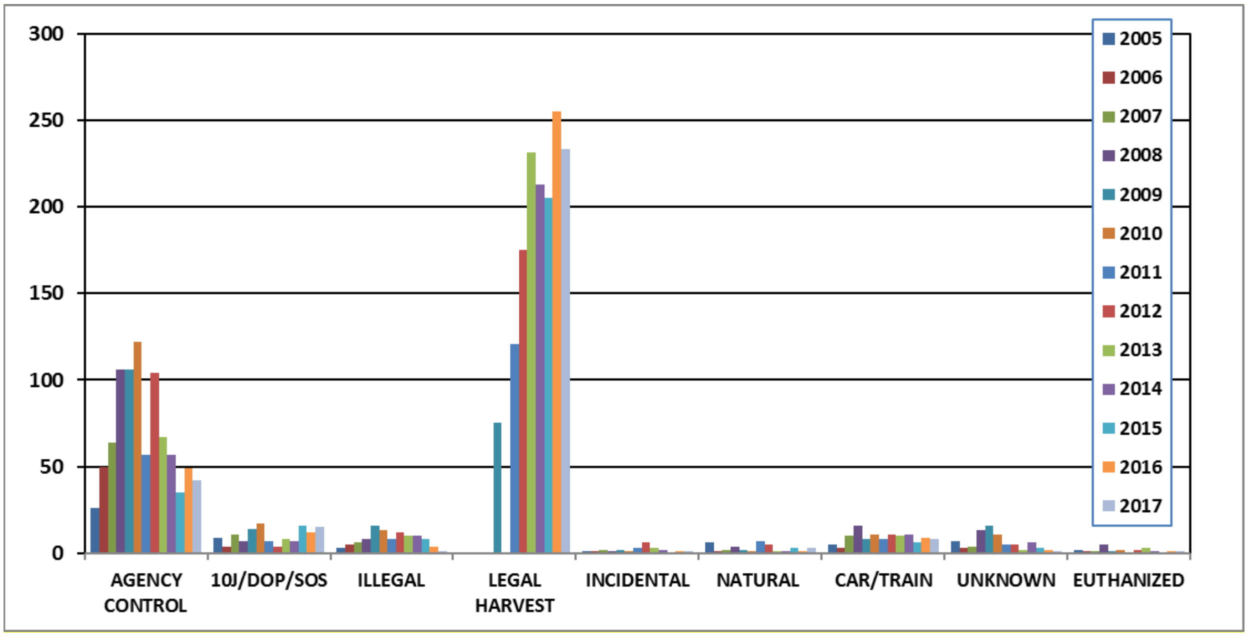


Figure 11. Minimum number of wolf mortalities documented by cause for gray wolves (2005-2017). Total number of documented wolf mortalities during 2017 was 305.

4. OUTREACH AND EDUCATION

FWP's wolf program outreach and education efforts are varied, but significant. Outreach activities take a variety of forms including field site visits, phone and email conversations to share information and answer questions, media interviews, and formal and informal presentations. FWP also prepared and distributed a variety of printed outreach materials and media releases to help Montanans become more familiar with the Montana wolf population and the state plan. The "Report a Wolf" application continued to generate valuable information from the public in monitoring efforts for existing packs and documenting wolf activity in new areas. Several reports were received through the website and others via postal mail and over the phone. Most wolf program staff spent some time at hunter check stations in FWP Regions 1-5 to talk with hunters about wolves, wolf management, and their hunting experiences.

5. FUNDING

5.1 Montana Fish, Wildlife & Parks Funding

Funding for wolf conservation and management in Montana is controlled by laws enacted by the state legislature. State laws also provide detailed guidance on some wolf management activities. The Montana Code Annotated (MCA) is the current law, and specific sections can be viewed at http://leg.mt.gov/bills/mca/index.html. Legislative bill language and history that has created or amended MCA sections can be accessed at http://leg.mt.gov/css/bills/Default.asp. Three sections of the MCA are of primary significance to wolf management and funding. These are:

MCA 87-5-132 Use of Radio-tracking Collars for Monitoring Wolf Packs
MCA 87-1-623 Wolf Management Account
MCA 87-1-625 Funding for Wolf Management

MCA 87-5-132 was created during the 2005 legislative session by Senate Bill 461. It has been amended twice, both times during the 2011 legislative session, by House Bill 363 and Senate Bill 348. This law requires capturing and radio-collaring an individual within a wolf pack that is active in an area where livestock depredations are chronic or likely.

MCA 87-1-623 was created during the 2011 Legislative Session by House Bill 363. This law requires that a wolf management account be set up and that all wolf license revenue be deposited into this account for wolf collaring and control. Specifically, it states that subject to appropriation by the legislature, money deposited in the account must be used exclusively for the management of wolves and must be equally divided and allocated for the following purposes: (a) wolf-collaring activities conducted pursuant to 87-5-132; and (b) lethal action conducted pursuant to 87-1-217 to take problem wolves that attack livestock.

MCA 87-1-625 was created during the 2011 Legislative Session by Senate Bill 348. This law required FWP to allocate $900,000 annually toward wolf management. "Management" in MCA 87-1-625 is defined as in MCA 87-5-102, which includes the entire range of activities that constitute a modern scientific resource program, including but not limited to research, census, law enforcement, habitat improvement, control, and education. The term also includes the periodic protection of species or populations as well as regulated taking. During the 2015 legislative session, Senate Bill 418 reduced this amount to $500,000 of spending authority.

Wolf management funding for state fiscal year 2017 (July 1, 2016 – June 30, 2017) consisted of $332,357 of federal PR funds, $357,759 of Montana wolf and general license dollars, and $365 from the Rocky Mountain Elk Foundation.

Funding was used to pay for FWP’s field presence to implement population monitoring, collaring, outreach, hunting, trapping, and livestock depredation response. During state fiscal year 2017, the wolf program had 5.5 FTE wolf specialists dedicated to wolf management, and 1 total FTE for 2 seasonal technicians to increase collaring efforts in wolf packs associated with livestock. FWP also renewed the financial agreement with Wildlife Services for their role in wolf depredation management efforts. Other wolf management services provided by FWP include law enforcement, harvest/quota monitoring, legal support, public outreach, and overall program administration. Exact cost figures have not been quantified for the value of these services.

5.2 USDA Wildlife Services Funding

Wildlife Services (WS) is the federal agency that assists FWP with wolf damage management. WS personnel conduct investigations of injured or dead livestock to determine if it was a predation event and, if so, what predator species was responsible for the damage. Based on WS determination, livestock owners may be eligible to receive reimbursement through the Montana Livestock Loss Program. If WS determines that the livestock depredation was a confirmed wolf kill or was a probable wolf kill, the livestock owner is eligible for 100% reimbursement on the value of the livestock killed based on USDA market value at the time of the investigation.

Under an MOU with FWP, the Blackfeet Nation (BN), and the Confederated Salish and Kootenai Tribes (CSKT), WS conducts the control actions on wolves as authorized by FWP, BN, and CSKT. Control actions may include radio-collaring and/or lethal removal of wolves implicated in livestock depredation events. FWP, BN, and CSKT also authorize WS to opportunistically radio-collar wolf packs that do not have an operational radio-collar attached to a member of the pack in order to fulfill the requirements of Montana State Statute 87-1-623.

As a federal agency, WS receives federal appropriated funds for predator damage management activities but no funding directed specifically for wolf damage management. Prior to Federal Fiscal Year (FFY) 2011, the WS Program in Montana received approximately $250,000 through the Tri-State Predator Control Earmark, some of which was used for wolf damage management operations. However, that earmark was completely removed from the federal budget for FFY 2011 and not replaced in FFY 2012-2017.

In FFY 2017, WS spent $278,642 conducting wolf damage management in Montana (not including administrative costs). The FFY 2017 expenditure included $168,642 Federal appropriations and $110,000 from FWP.

6. PERSONNEL AND ACKNOWLEDGEMENTS

The 2017 FWP wolf specialist team was comprised of Diane Boyd, Nathan Lance, Abigail Nelson, Mike Ross, Tyler Parks, and Ty Smucker. Wolf specialists work closely with regional wildlife managers in FWP regions 1-5, including Neil Anderson, Howard Burt, Ray Mule, Graham Taylor, and Mike Thompson, as well as Wildlife Management Bureau Chief, John Vore, and Carnivore and Furbearer Coordinator, Bob Inman. FWP Helena and Wildlife Health Lab staff contributed time and expertise including Keri Carson, Caryn Dearing, Missy Erving, Justin Gude, Quentin Kujala, Greg Lemon, Ken McDonald, Adam Messer, Kevin Podruzny, and Jennifer Ramsey. The wolf team is part of a much bigger team of agency professionals that make up Montana Fish, Wildlife & Parks including regional supervisors, biologists, game wardens, information officers, front desk staff, and many others who contribute their time and expertise to wolf management.

During 2017, the Montana wolf management program benefited from the contributions of seasonal technicians Molly Parks and Kris Boyd along with intern Shelby Smith. The Montana wolf management volunteer program was very fortunate to have Jeremy SunderRaj, Justine Vallieres, and Story Warren. Also, a thank you to Blackfoot Challenge range riders: Eric Graham, Jordan Mannix, Kelsey Bailey, and Sigrid Olson. We thank the Tom Miner Basin Association and Range riders for wolf monitoring information and great communication. We thank the Beartooth Backcountry Horsemen's Association for their interest and efforts in monitoring wolf activity in the Stillwater and the Beartooths.

We thank Northwest Connections for their avid interest and help in documenting wolf presence and outreach in the Swan River Valley. We thank Swan Ecosystem Center for their continued interest and support. We also thank the Blackfoot Challenge for their contributions and efforts toward monitoring wolves in the Blackfoot Valley. We thanks Kyran Kunkle of American Prairie Reserve for his help initiating and coordinating a range rider program on private and public land along the Southern Rocky Mountain Front. We also thank Kathy Robinson who was the range rider on this effort and was instrumental in working with local producers to monitor livestock and predator activity in the area.

We thank Confederated Salish and Kootenai Tribal biologists Stacey Courville and Shannon Clairmont, and Blackfeet Tribal biologist Dan Carney, wildlife technician Dustin Weatherwax, and wardens Glenn Hall and Jeff Horn for capturing and monitoring wolves in and around their respective tribal reservations.

We acknowledge the work of the citizen-based Montana Livestock Loss Board which oversees implementation of Montana's reimbursement program and the conflict prevention grant money, and we thanks the LLB's coordinator, George Edwards.

USDA APHIS WS investigates all suspected wolf depredations on livestock and under the authority of FWP, carries out all livestock depredation-related wolf damage management activities in Montana. We thank them for contributing their expertise to the state's wolf program and for their willingness to complete investigations and carry out lethal and non-lethal damage management and radio-collaring activities in a timely fashion. We also thank WS for assisting with monitoring wolves in Montana. WS personnel involved in wolf management in Montana during 2017 included state director John Steuber; western district supervisor Kraig Glazier; eastern district supervisor Dalin Tidwell; western assistant district supervisor Chad Hoover; eastern assistant district supervisor Alan Brown; wildlife disease biologist Jared Hedelius; wildlife biologist Alexandra Few; helicopter pilot Eric Waldorf; helicopter/airplane pilots Tim Graff, John Martin and Stan Colton; airplane pilots Tom Hlavnicka, Guy Terrill, Justin Ferguson, and Scott Snider; wildlife specialists Denny Biggs, TJ Dorval, Mike Hoggan, Cody Knoop, Jordan Linnell, John Maetzold, Graeme McDougal, John Miedtke, Kurt Miedtke, Brian Noftsker, Ted North, Scott Olson, Jim Rost, Bart Smith, Pat Sinclair, and Danny Thomason.

The Montana Wolf Management program field operations also benefited in a multitude of ways from the continued cooperation and collaboration of other state and federal agencies and private interests such as the USDA Forest Service, Montana Department of Natural Resources and Conservation (“State Lands”), U.S. Bureau of Land Management, Plum Creek Timber Company, Glacier National Park, Yellowstone National Park, Idaho Fish and Game, Wyoming Game and Fish, Nez Perce Tribe, Canadian Provincial wildlife professionals, Turner Endangered Species Fund, People and Carnivores, Wildlife Conservation Society, Keystone Conservation, Boulder Watershed Group, Big Hole Watershed Working Group, the Madison Valley Ranchlands Group, the upper Yellowstone Watershed Group, the Blackfoot Challenge, Tom Miner Basin Association, and the Granite County Headwaters Working Group.

We deeply appreciate and thank our pilots whose unique and specialized skills, help us find wolves, get counts, and keep us safe in highly challenging, low altitude mountain flying situations. They include Joe Rahn (FWP Chief Pilot), Neil Cadwell (FWP Pilot), Ken Justus (FWP Pilot), Trever Throop (FWP Pilot), Mike Campbell (FWP Pilot), Rob Cherot (FWP Pilot), Jim Pierce (Red Eagle Aviation, Kalispell), Roger Stradley (Gallatin Flying Service, Belgrade), Steve Ard (Tracker Aviation Inc., Belgrade), Lowell Hanson (Piedmont Air Services, Helena), Dave Horner (Red Eagle Aviation), Joe Rimensberger (Osprey Aviation, Hamilton), and Mark Duffy (Central Helicopters, Bozeman). We also thank Quicksilver Aviation for their safe and efficient helicopter capture efforts.

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APPENDICES

APPENDIX 1

MONTANA CONTACT INFORMATION

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USDA Wildlife Services

(to request investigations of injured or dead livestock):

John Steuber
USDA WS State Director, Billings
(406) 657-6464 (w)

Kraig Glazier
USDA WS West District Supervisor, Helena
(406) 458-0106 (w)

Dalen Tidwell
USDA WS East District Supervisor, Columbus
(406) 657-6464 (w)

TO REPORT A DEAD WOLF OR POSSIBLE ILLEGAL ACTIVITY:

Montana Fish, Wildlife & Parks

- Dial 1-800-TIP-MONT (1-800-847-6668) or local game warden

TO SUBMIT WOLF REPORTS ELECTRONICALLY AND TO LEARN MORE ABOUT THE MONTANA WOLF PROGRAM, SEE:

- http://fwp.mt.gov/fishAndWildlife/management/wolf/

MONTANA FISH WILDLIFE & PARKS
ADMINISTRATIVE REGIONS

STATE HEADQUARTERS
MT Fish, Wildlife & Parks
1420 E 6th Avenue
PO Box 200701
Helena, MT 59620-0701
(406) 444-2535

REGION 1
490 N Meridian Rd
Kalispell, MT 59901
(406) 752-5501

REGION 2
3201 Spurgin Rd
Missoula, MT 59804
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REGION 3
1400 South 19th
Bozeman, MT 59718
(406) 994-4042

HELENA Area Res Office (HARO)
930 Custer Ave W
Helena, MT 59620
(406) 495-3260

BUTTE Area Res Office (BARO)
1820 Meadowlark Ln
Butte, MT 59701
(406) 494-1953

REGION 4
4600 Giant Springs Rd
Great Falls, MT 59405
(406) 454-5840

LEWISTOWN Area Res Office (LARO)
215 W Aztec Dr
PO Box 938
Lewistown, MT 59457
(406) 538-4658

REGION 5
2300 Lake Elmo Dr
Billings, MT 59105
(406) 247-2940

REGION 6
54078 US Hwy 2 W
Glasgow, MT 59230
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HAVRE Area Res Office (HvARO)
2165 Hwy 2 East
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REGION 7
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PO Box 1630
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APPENDIX 2

RESEARCH, FIELD STUDIES, AND PROJECT PUBLICATIONS

Each year in Montana, there are a variety of wolf-related research projects and field studies in varying degrees of development, implementation, or completion. These efforts range from wolf ecology and predator-prey relationships to wolf-livestock relationships, policy, or wolf management. In addition, the findings of some completed projects get published in the peer-reviewed literature. The 2017 efforts are summarized below, with updates or project abstracts.

1. IMPROVING ESTIMATION OF WOLF RECRUITMENT AND ABUNDANCE, AND DEVELOPMENT OF AN ADAPTIVE HARVEST PROGRAM FOR WOLVES IN MONTANA.

Status: In Progress

The full 2017 report is included on the following pages.

Improving Estimation of Wolf Recruitment and Abundance, and Development of an Adaptive Harvest Management Program for Wolves in Montana

Federal Aid in Wildlife Restoration Grant W-161-R-1

Annual interim report, March 2018

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State: Montana
Agency: Fish, Wildlife & Parks
Grant: Montana wolf monitoring study
Grant number: W-161-R-1
Time period: January 1, 2017−December 31, 2017

INTRODUCTION

Wolves (*Canis lupus*) were reintroduced in the northern Rocky Mountains (NRM) in 1995, and after rapid population growth were delisted from the endangered species list in 2011. Since that time, states in the NRM have agreed to maintain populations and breeding pairs (a male and female wolf with 2 surviving pups by December 31; USFWS 1994) above established minimums (≥150 wolves and ≥15 breeding pairs within each state). Montana estimates population size every year using patch occupancy models (POM; MacKenzie et al. 2002, Rich et al. 2013, Miller et al. 2013, Bradley et al. 2015), however, these estimates are sensitive to pack size and territory size, and were developed pre-harvest. Reliability of future estimates based on POM will be contingent on accurate information on territory size, overlap, and pack size, which may be affected by harvest. Additionally, breeding pairs, which has proven to be an ineffective measure of recruitment, are determined via direct counts. Federal funding for wolf monitoring has ended in states where wolves are delisted, and future monitoring will not be able to rely on intensive counts of the wolf population. Furthermore, intensive, field-based monitoring has become cumbersome and less effective since the population has grown. With the implementation of harvest, it is pertinent to predict the effects of harvest on the wolf population and continue to monitor to determine effectiveness of management actions to make informed decisions regarding hunting and trapping seasons.

STUDY OBJECTIVES

Our 4 study objectives are to:

1. Improve estimation of recruitment.

2. Improve and maintain calibration of wolf abundance estimates generated through POM.

3. Develop a framework for dynamic, adaptive harvest management based on achievement of objectives 1 & 2.

4. Design a targeted monitoring program to provide information needed for robust estimates and reduce uncertainty in the AHM paradigm over time.

Two PhD students are addressing the 4 study objectives as part of Project 1 (Sarah Sells) and Project 2 (Allison Keever; Fig. 1).

DELIVERABLES

1. A method to estimate recruitment for Montana's wolf population that is more cost effective and biologically sound than the breeding pair metric (Project 2, A. Keever).

2. Models to estimate territory size and pack size that can keep POM estimates calibrated to changing environmental and management conditions for wolves in Montana (Project 1, S. Sells).

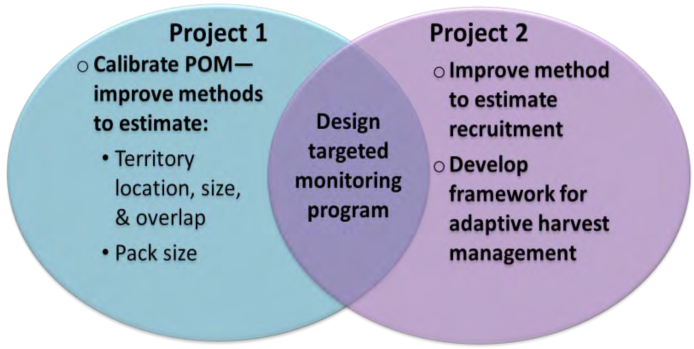

Fig. 1. Objectives for this project are being addressed under 2 separate projects.

3. An adaptive harvest management model that allows the formal assessment of various harvest regimes and reduces uncertainty over time to facilitate adaptive management of wolves (Project 2, A. Keever).

4. A recommended monitoring program for wolves to maintain calibration of POM estimates, determine effectiveness of management actions, and facilitate learning in an adaptive framework (Projects 1 & 2).

LOCATION

This study encompasses wolf distribution in Montana and Idaho (Fig. 2). Additional data will come from Yellowstone National Park for the territory models developed under objective 2.

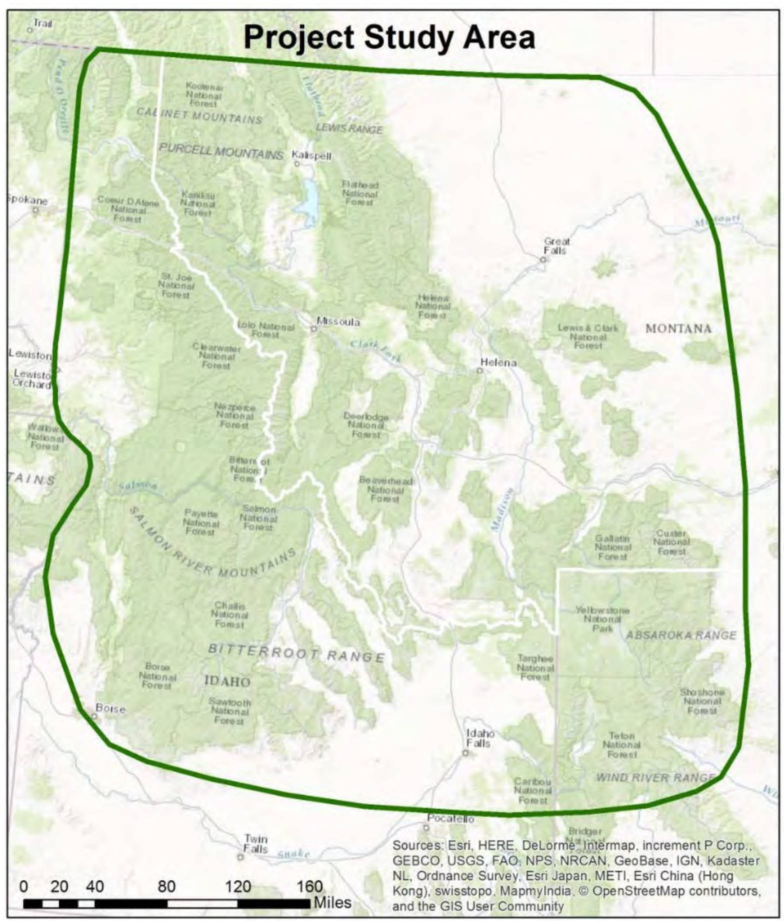

Fig. 2. The project study area includes wolf distribution in Montana and Idaho, as well as Yellowstone.

GENERAL PROGRESS

Projects 1 & 2, Year 1: We (S. Sells & A. Keever) started our PhD programs in January 2015 (Fig. 3). Much of year 1 was devoted to literature reviews on animal behavior, carnivores, modeling, optimal foraging, etc. and determining approaches for the dissertations. We also formed and held multiple meetings with our committees, worked on completing coursework requirements, and finalized research statements. Additional efforts focused on communicating with wolf specialists, identifying target packs for collaring, managing collar orders and data, and helping coordinate contracts and capture plans for winter aerial captures for January and February 2016. We also met with wolf specialists in the field to learn more about the wolves in each region, and coordinated and held meetings with the specialists to plan future project efforts.

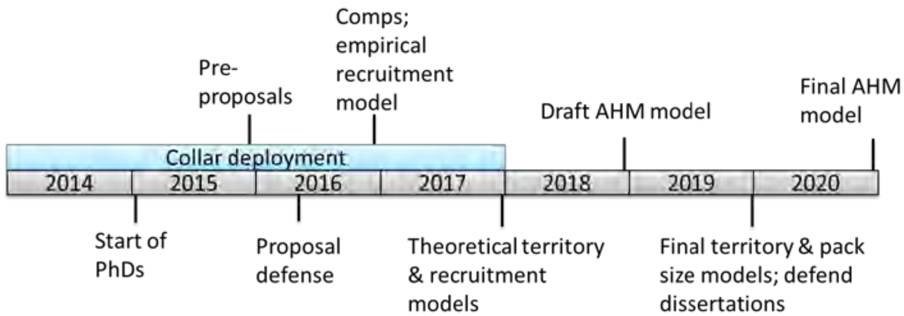

Fig. 3. Project timeline.

Project 1 (S. Sells): In year 2, I continued most activities from year 1, including conducting literature searches, taking classes, holding committee meetings, communicating with wolf specialists, managing collar orders, managing data, etc. I also began working on the theoretical territory models. My primary focus was meeting project and university requirements and deadlines, including defending my proposal and passing my comprehensive exams. I also joined the wolf specialists to assist with a month of trapping.

Year 3 was primarily devoted to preparing the theoretical territory models. I presented draft results at 5 conferences. In addition to completing more coursework, I continued working with FWP and collar manufacturers as the point person on ordering collars, troubleshooting a growing set of issues with the collars, and managing collar records. I continued coordinating data management and collection from deployed collars and communicating with wolf specialists on all trapping and collar-related topics. I also spent 2 weeks assisting wolf specialists with trapping.

Project 2 (A. Keever): In year 2 I continued literature reviews, completed coursework, and meeting university requirements. I defended my proposal and was studying for my comprehensive exams. Another focus was on the empirical recruitment model. I began developing the model that I had outlined in my proposal. I also spent 1 month assisting wolf specialists with trapping.

Year 3 I completed the empirical recruitment model code and tested the model with simulated data. Much of my time was spent compiling and formatting the data needed to estimate recruitment. I presented preliminary results at 2 conferences. I also passed my comprehensive exams and spent 2 weeks assisting wolf specialists with trapping.

Deliverables and updates: Project deliverables will include an empirical recruitment model; theoretical territory, group size, and recruitment models; draft and final AHM models; and final territory and pack size models. We have been working on deliverables of the empirical recruitment model (A. Keever) and the theoretical territory models (S. Sells) towards meeting objectives 1 and 2. We each describe our progress towards these deliverables in this report. (Additional details on objectives 3 and 4 are available in the 2016 report.)

DATA COLLECTION SUMMARY

Trapping efforts by Montana Fish, Wildlife and Parks have continued since 2014:

- There have been 66 successful captures directly related to this project through 2017.
- Collars were deployed in approximately 46 packs (this number is fluid as wolves disperse).
- Using ground and aerial captures:
  - 10 collars were deployed in 2014.
  - 14 collars were deployed in 2015.
  - 27 collars were deployed in 2016.
  - 16 collars were deployed in 2017.
- These collars have yielded >26,000 locations of wolves (Fig. 4).
- After collar removals, harvests, other mortalities, and some collar losses (e.g., through dropped collars), 28 collars remained deployed at the end of 2017.
- Many of the collars began experiencing major performance issues in 2017, however. Of the 28 deployed collars, only 9 were functional as of December 2017 (see below).

Collaring efforts will continue via ground and aerial captures through 2018.

The project began experiencing a growing set of technical issues with collars in 2017. Many collars began failing to send reliable transmissions to the satellite service, and eventually many stopped transmitting altogether. After 3 months without a fix, a collar is considered to have malfunctioned and is deactivated. In summary:

- 20 collars have failed while deployed, 16 of which are still deployed.
  - 15 collars worked for 1 – 2.25 years before failing.
    - 1 collar was recovered and had VHF failure.
    - 2 collars were recovered and had battery failure.
    - 12 collars are still deployed.
  - 4 collars worked for <1 year (4 – 11 months) before failing and are still deployed.
  - 1 collar never worked after deployment and was recently recovered.

- 3 more collars are approaching the 3 month deadline without a transmission and will be deactivated soon.
- 9 collars are functional or mostly functional as of December 2017.

We are working with Lotek to return all collars that have not yet been deployed. These will be replaced with collars that are expected to provide better performance based on what Lotek has learned from these recent failures. We consider these collar failures and challenges all the more impetus to reduce needs for future collaring efforts; our work will help achieve this goal.

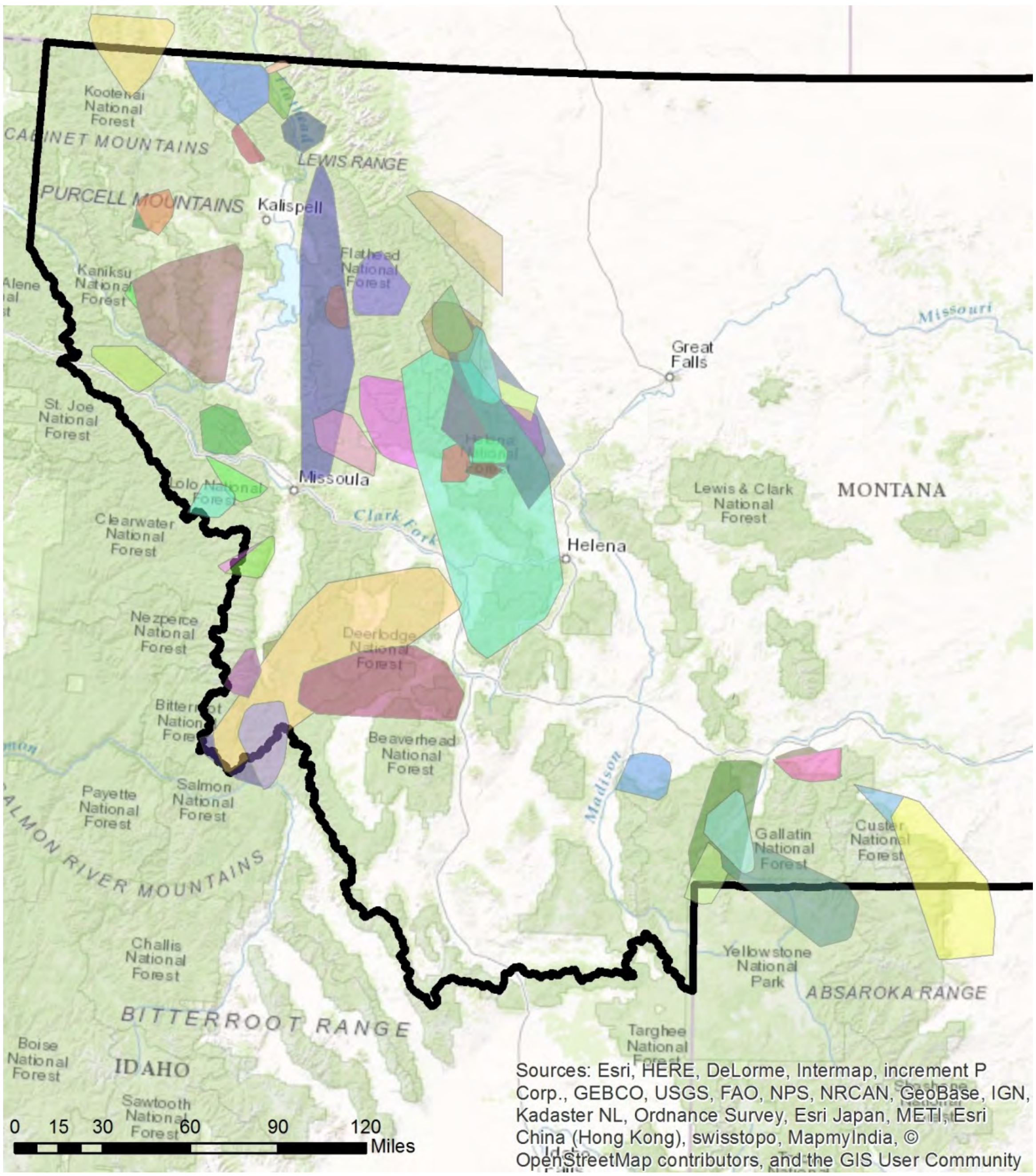

Fig. 4. Locations of wolves collared for this project, 2014−2016. Colors represent different wolves. Note that some polygons include dispersal from original pack's territory.

PROGRESS ON OBJECTIVES

Objective 1: Improve estimation of recruitment—*Allison Keever, Project 2*

1.1 Background

Estimating recruitment (i.e., number of young produced that survive to an age at which they contribute to the population) of wolves can be difficult due to their complex social structure. Wolves are cooperative breeders, and pack dynamics (e.g., pack tenure, breeder turnover, and number of non-breeding helpers) can affect recruitment and pup survival (e.g., Ausband et al. 2015). Cooperative breeding often relies on the presence of non-breeding individuals that help raise offspring (Solomon and French 1997), and reduction in group size can lead to decreased recruitment in cooperative breeders (Sparkman et al. 2011, Stahler et al. 2013). Human-caused mortality through both direct and indirect means (Ausband et al. 2015) and prey biomass per wolf (Boertje and Stephenson 1992) have been shown to affect recruitment. As a result, it will be important to consider the effects of harvest, pack dynamics, wolf density, and prey availability on recruitment.

Further challenges of estimating recruitment include the size of the wolf population and limited time and funding for monitoring. Currently, FWP documents recruitment through visual counts of breeding pairs (a male and female wolf with 2 surviving pups by December 31; U.S. Fish and Wildlife Service 1994). These counts, however, are likely incomplete due to the large number of wolves in the population. Federal funding for wolf monitoring in Montana and Idaho is no longer available. States therefore fund their own monitoring programs, and future monitoring will not be able to rely on intensive counts. A breeding pair estimator (Mitchell et al. 2008) could be used to estimate breeding pairs, but this requires knowing pack size; such data are hard to collect given the size of the wolf population. Additionally, the breeding pair metric is an ineffective measure of recruitment because it provides little insight into population growth rate or the level of harvest that could be sustained. Recruitment could be estimated by comparing visual counts at the den site to winter counts via aerial telemetry (Mech et al. 1998) or by marking pups at den sites (Mills et al. 2008). An alternative method could include non-invasive genetic sampling (Ausband et al. 2015) at predicted rendezvous sites (Ausband et al. 2010). These methods, however, may not be feasible on large scales due to budget and staff constraints. Existing monitoring efforts yield insufficient data to estimate recruitment using traditional methods; therefore a new approach is needed that does not rely on extensive data.

1.2 Goals and General Approach

Our objective is to develop an approach to estimate recruitment that is more tractable, cost effective, and biologically credible than the breeding pair metric. Collar and count data are currently collected for on-going monitoring, however these data may not be available or at least not as many data available moving forward. Therefore, our goal is to create a model that can be flexible in the amount of data required to estimate recruitment and also evaluate the accuracy and precision of estimates with varying amounts of data. Integrated population models can be a useful tool for demographic analyses from limited data sets, and can increase precision in estimates (Besbeas et al. 2002). We will develop a per capita integrated population model (hereafter IPM) to estimate recruitment and evaluate the relationship between recruitment and factors that may cause spatial and temporal variation in wolf recruitment. We will use collar, count and hunter survey data from 2007–2016 in Montana to estimate recruitment. We will also use a simulation study to evaluate how many data are needed to get reliable estimates using this method to see if it will be cost effective to implement.

The resulting statistical model will relate covariates and recruitment. It will not, however, improve understanding of the mechanisms that cause recruitment to change. Recruitment depends on a pack's success in breeding and giving birth, as well as litter size and pup survival. Whether a pack successfully breeds and gives birth or not is primarily determined by the survival of the breeding pair in the pack. Conversely, pup survival may be affected by helper presence, prey availability, disease outbreaks, and human-caused mortality (Goyal et al. 1986, Boertje and Stephenson 1992, Johnson et al. 1994, Mech and Goyal 1995, Fuller et al. 2003, Ausband et al. 2015). Unfortunately, there are few data to estimate the contribution of those factors to overall pup recruitment, so we will also develop a mechanistic model of recruitment to theoretically explore the effects of human-caused mortality, prey availability, multiple litters per pack, disease outbreaks, and group size on the different components of recruitment. The probability a pack successfully breeds and reproduces, litter size per pack, and pup survival all determine pup recruitment. Hypotheses about how factors such as disease, harvest, or prey availability affect these parameters can be explored using liner or non-linear models and then multiplied together. Different models can be developed that represent different hypotheses. Those different hypotheses will result in different predictions of recruitment if those hypotheses were correct. The model predictions can be compared to estimated recruitment from the IPM to determine which hypotheses have most support.

1.3 Methods

We are currently developing the IPM model to estimate recruitment in program R (R Core Team 2014) in a Bayesian framework using package R2jags (Su and Yajima 2015) to communicate with JAGS (Plummer 2003). The IPM model will allow us to evaluate the factors that cause spatial and temporal variation in recruitment and, through use of a simulation study, determine data requirements for estimating recruitment. Recruitment data are not available across Montana, so we will use the hunter survey, group count, and GPS and VHF collar data that are currently available from ongoing monitoring. The IPM will have a 1) POM model to estimate abundance, 2) survival model, 3) recruitment model, 4) a population-level model to relate changes in abundance over time with survival and recruitment, and 5) a group-level model to relate changes in group size over time with survival and recruitment (Fig. 1.1). This IPM framework is unique in that it adds a group-level model to account for the social structure of wolves and its influence on recruitment. We are evaluating the efficacy of the IPM model by simulating data to test how many data are required for accurate estimates of recruitment. Then, we will use hunter survey, group count, and collar data to estimate recruitment across the state of Montana.

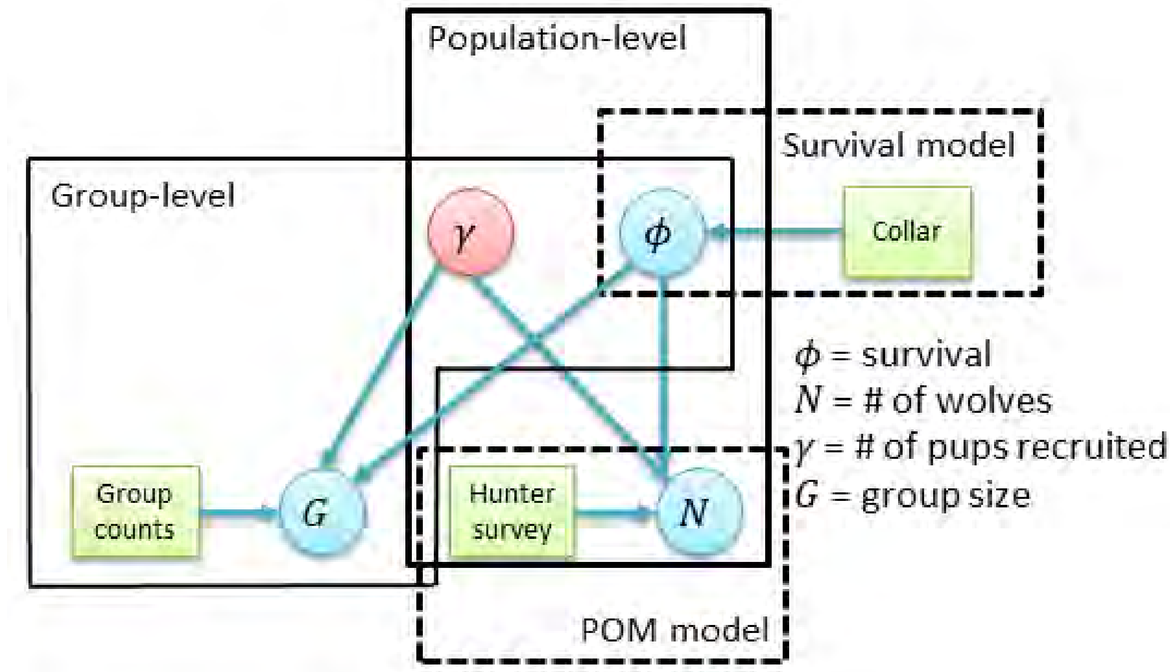

Fig. 1.1. Simplified directed acyclic graph of a per capita integrated population model for wolves that includes population-level and group-level state-space models. The boxes represent data sources and the circles represent parameters.

1.3.1 POM model

We will use the same occupancy modeling framework that FWP currently applies across the state using hunter survey data to estimate abundance of the wolf population. We will use a dynamic false-positive occupancy model (MacKenzie et al. 2002; Miller et al. 2013, Rich et al. 2013; Bradley et al. 2015) to estimate the area occupied by wolves. We will then use GPS collar data from 2008-2009 (Rich et al. 2012) to estimate mean territory size. The number of packs is then the area occupied by wolves divided by the mean territory size. To estimate abundance we will take the number of packs and multiply by the average group size of a wolf pack. Group size will be estimated from the group count data while accounting for observation error for each year. We will also account for territory overlap like FWP does for their abundance estimates. Eventually, work from current research (Objective 2) on territory size and group size will be used in place of average territory and group size to improve estimates of abundance in the IPM model.

1.3.2 Survival model

We will estimate survival using a discrete-time proportional hazards model, or a complementary log-log (cloglog) model. We will use biologically relevant discrete periods for analyses such as the denning period (April-May), rendezvous period (June-August), and the hunting/trapping season (September-March). GPS and VHF collared wolves from 2007-2016 will provide the known-fate information needed to estimate survival. These data, however, may have inherent sampling bias. Most collared wolves from this time period are targeted because they are livestock conflict packs. These data would bias survival low. To account for this we could use an informative prior on survival and weight the collars so that research collars have more influence on the posterior estimate of survival than collars from livestock conflict packs. Or, we could also only use collars deployed for research purposes to account for this bias in survival.

1.3.3 Recruitment model

We will evaluate factors that explain the spatial and temporal variation in recruitment using generalized linear models with a log link function. We will develop *a priori* hypotheses regarding how factors such as human-caused mortality rates, landowner-type (e.g., public vs. private), road density, land cover type, elevation, and group size affect recruitment of wolves. We will test these hypotheses using the IPM in Montana.

1.3.4 Population level

Changes in abundance over time are a function of births, deaths, immigration, and emigration. We have information about abundance and survival for wolves in Montana, therefore we can essentially solve for recruitment. Because the pack is the reproductive unit, at the population level we will account for immigration and emigration by including colonization and extinction of packs which will be informed by the occupancy model. Lone wolves that immigrate into the population can be ignored. Wolves joining or dispersing from a pack will be accounted for at the group level.

1.3.5 Group-level model

A typical IPM framework does not account for animals with social structure and cooperative breeding. Therefore, we will add a group level model that explicitly accounts for the social structure of wolves. This framework allows us to estimate recruitment at the pack level as well as the population level which improves estimation of recruitment. We will also include dispersal from the pack modeled using recent literature on dispersal rates of wolves in the U.S. northern Rocky Mountains (Jimenez et al. 2017). Changes in group size will be a result of recruitment, survival, and dispersal.

The main objective of this work is to provide a method to estimate recruitment that is more cost effective, which means it cannot require a lot of data. This framework requires group count data to estimate recruitment. These data, however, may be too costly to collect in the future. The IPM is flexible and could still estimate recruitment with only the population-level. Therefore, we will test the IPM without the group-level as well which would eliminate the need for group count data.

1.3.6 Data simulation

Our goal is to provide a model to estimate recruitment that is more cost effective. For a method to be cost effective, and therefore useful for monitoring, it cannot rely on a lot of data that are expensive to collect. To determine whether the IPM model would be useful in the future we evaluated the amount of data that would be needed to get reliable estimates of recruitment using a simulation study. We simulated a wolf population for 10 years and then sampled from the population. To do this we first generated 100 wolf packs using a Poisson distribution with an average pack size of 4 wolves. We then randomly generated survival, recruitment, and dispersal rates using a uniform distribution with a range of biologically realistic rates. This allowed for yearly variation in the demographic rates, which we could then record as our truth. The simulated wolves then survived and reproduced based on the demographic rates we generated, with stochasticity using Poisson and binomial distributions for reproduction and survival/dispersal, respectively. We then added up the number of wolves within packs to get truth for total abundance.

After simulating the wolf population, we then randomly sampled 50, 25, and 12 packs of the 100 for group count data. We also added observation error, so our sample of packs is also a sample of wolves within the pack. For survival data we used our truth survival for each year and generated 50 known-fate observations of wolves incorporating stochasticity using the binomial distribution. We then sampled 20, 10, and 5 of those observations which represent our collar data. We used these data in the IPM model to estimate recruitment and determine how well it matched our truth we used to simulate the data.

1.4 Preliminary Results

With simulated data we know "truth," and can compare our estimates to truth. We ran the IPM model with occupancy fixed to evaluate the amount collar and group count data needed for accurate estimates of recruitment. We also compared our estimates of survival, group size, and abundance to truth. We found that datasets with at least 10 collars and 25 group counts were precise for estimating recruitment (Fig. 1.2). Generally, all datasets except the dataset with 5 collars and 12 group counts provided accurate estimates of recruitment with a % error of < 20% (Table 1.1). All datasets provided approximately the same accuracy of abundance estimates (Fig. 1.3), and only the dataset with 5 collars resulted in inaccurate estimates of survival (Fig. 1.4).

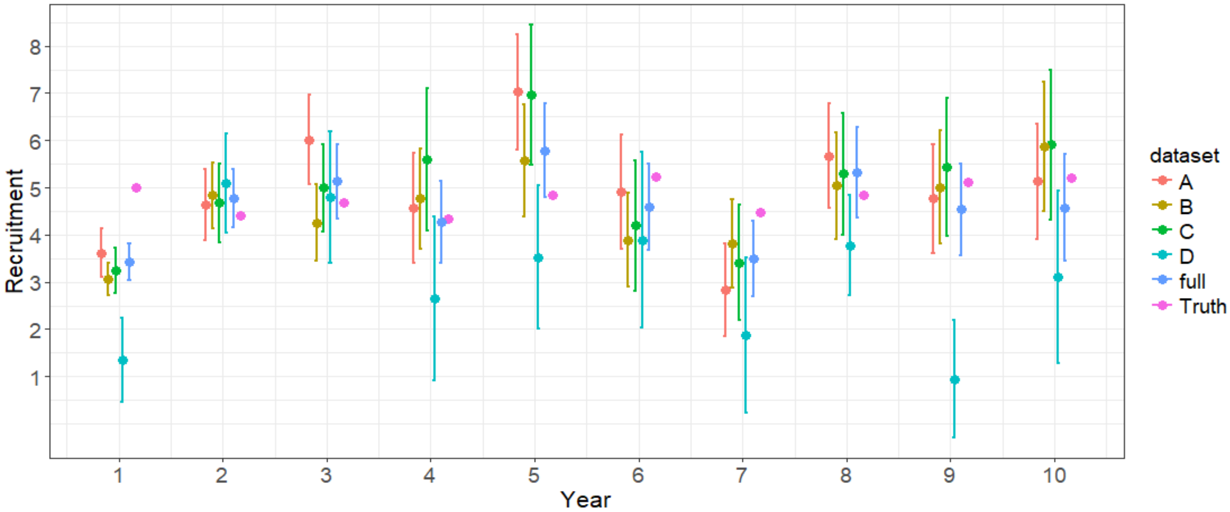

Fig. 1.2: Estimates of recruitment (pups per pack) generated from varying amounts of data compared to truth: full dataset (50 group counts; 20 collars), A dataset (25 group counts; 20 collars), B dataset (50 group counts; 10 collars), C dataset (25 group counts; 10 collars), and D dataset (12 group counts; 5 collars).

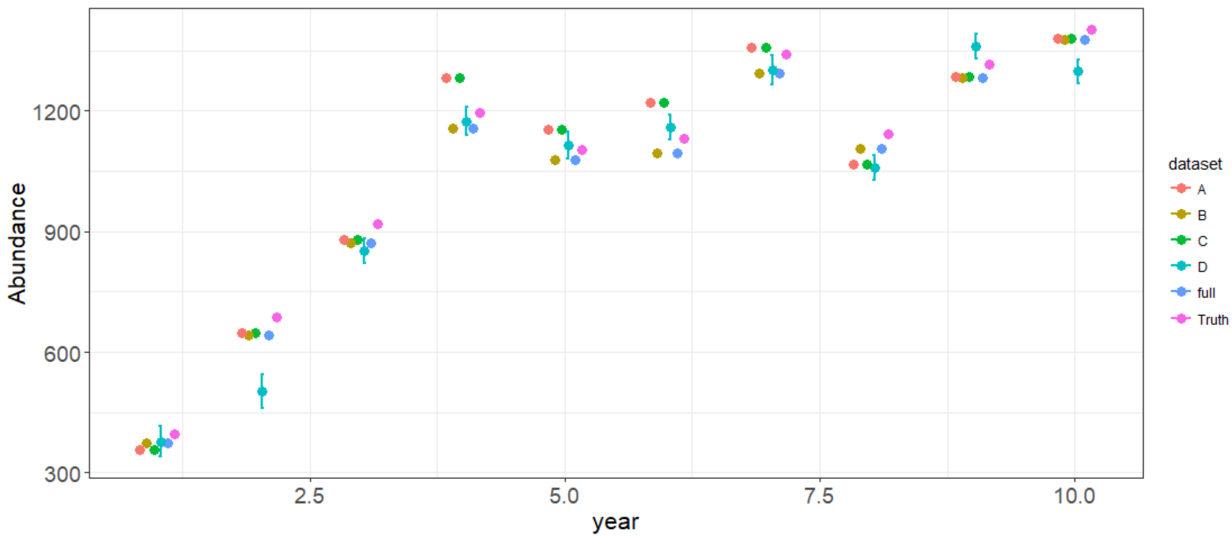

Fig. 1.3: Estimates of abundance generated from varying amounts of data compared to truth: full dataset (50 group counts; 20 collars), A dataset (25 group counts; 20 collars), B dataset (50 group counts; 10 collars), C dataset (25 group counts; 10 collars), and D dataset (12 group counts; 5 collars).

Table 1.1: % error of recruitment estimates from truth from varying amounts of data: full dataset (50 group counts; 20 collars), A dataset (25 group counts; 20 collars), B dataset (50 group counts; 10 collars), C dataset (25 group counts; 10 collars), and D dataset (12 group counts; 5 collars).

Full dataset	A dataset	B dataset	C dataset	D dataset
13.8%	18.0%	14.2%	19.4%	38.5%

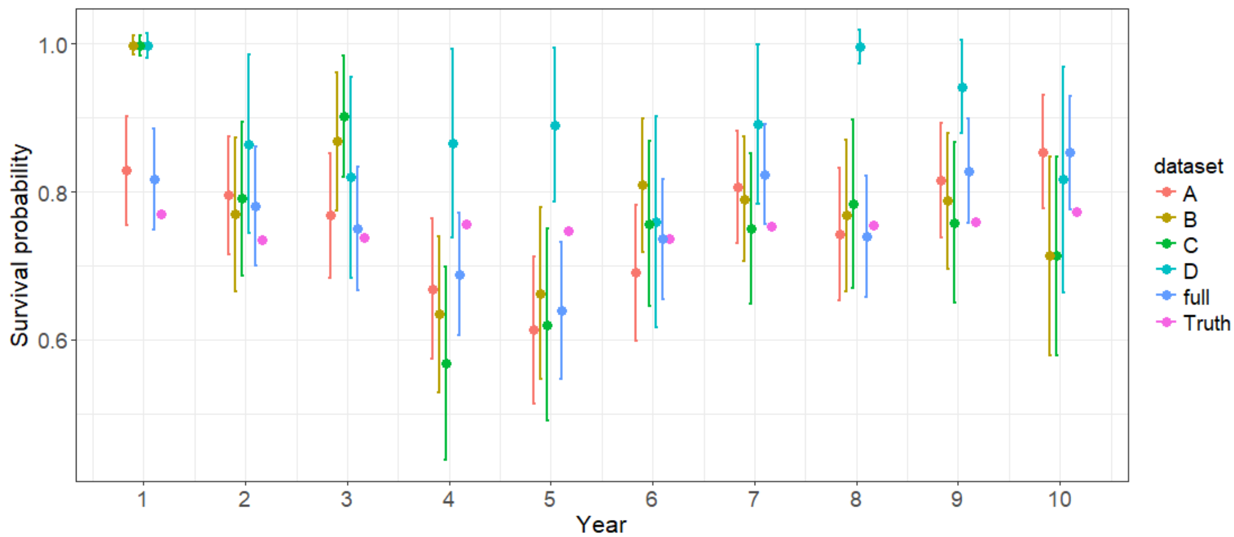

Fig. 1.4: Estimates of survival generated from varying amounts of data compared to truth: full dataset (50 group counts; 20 collars), A dataset (25 group counts; 20 collars), B dataset (50 group counts; 10 collars), C dataset (25 group counts; 10 collars), and D dataset (12 group counts; 5 collars).

1.5 Summary and next steps

The objective of this work is to provide a method to estimate recruitment that is both biologically credible and cost effective. The main determinant of whether this method will be cost effective is the amount of data required to estimate recruitment. The IPM can be a viable method to estimate recruitment because reliable estimates are generated using only 12-25 group counts and 10 collars. Further, if group count data are too costly to collect, the model can be adjusted to eliminate the need for group count data by removing the group-level model. Our next step will be to test the model without the group-level and evaluate the accuracy of recruitment estimates. The tradeoff between resources spent collecting data and accuracy of estimates generated from those data can then be assessed.

The other objective of this work was to provide a method that is more biologically credible than the breeding pair metric. The breeding pair metric estimates the probability a pack contains a breeding pair and does not provide detailed information on recruitment. The IPM model, which has been developed to account for wolves' social structure, is a method that provides accurate estimates of recruitment that we can use to answer biological questions about spatial and temporal variation in recruitment. This information can then be used to help inform harvest decisions.

We have recently completed data formatting and will begin running models to estimate recruitment of wolves across Montana. We will test *a priori* hypotheses about the factors that cause spatial and temporal variation in recruitment and use model selection to determine which hypotheses have most support. Then, we will apply the model in Idaho using the same types of data sources and compare model estimates of recruitment with field-based recruitment data as an external test of the model.

Objective 2: Improve and maintain calibration of wolf abundance estimates generated through POM—*Sarah Sells, Project 1*

2.1 Introduction

Monitoring is a critical, yet challenging, management tool for gray wolves. Since delisting of wolves in 2011, monitoring results help FWP set management objectives and communicate with stakeholders and the public. Monitoring any large carnivore is challenging, however, due to their elusive nature and naturally low densities (Boitani et al. 2012). This is particularly true for wolves due to increasing populations, decreasing funding for monitoring, and changing behavioral dynamics with harvest.

Abundance estimates are a key component of monitoring (Bradley et al. 2015). Abundance is currently estimated in Montana with 3 parameters: area occupied, average territory size, and annual average pack size (Fig. 2.1, Bradley et al. 2015). Area occupied is estimated with a Patch Occupancy Model (POM) based on hunter observations and field surveys (Miller et al. 2013, Bradley et al. 2015). Average territory size is assumed to be 600 km^2 with minimal overlap, based on past work (Rich et al. 2012). Annual average pack size is estimated from monitoring results. Total abundance (N) is then calculated as: $N = (\text{area occupied}/\bar{x}\ \text{territory size}) \times \bar{x}\ \text{pack}$.

Whereas estimates of area occupied from POM are expected to be reliable (Miller et al. 2013, Bradley et al. 2015), reliability of abundance estimates hinge on key assumptions about territory size, territory overlap, and pack size (Bradley et al. 2015). Assumptions of fixed territory size and minimal overlap are simplistic; in reality, territories vary spatiotemporally (Uboni et al. 2015). This variability is likely even greater under harvest (Brainerd et al. 2008). Meanwhile, pack size estimates assume all packs are located and accurately counted each year, which is no longer possible due to the number of packs and declining funding for monitoring (Bradley et al. 2015). Since implementation of harvest in 2009, several factors have further compounded these challenges and decreased accuracy of pack size estimates. First, whereas larger packs are generally easier to find and monitor, average pack size has decreased since harvest began (Bradley et al. 2015). Difficult-to-detect smaller packs may be more likely to be missed altogether,

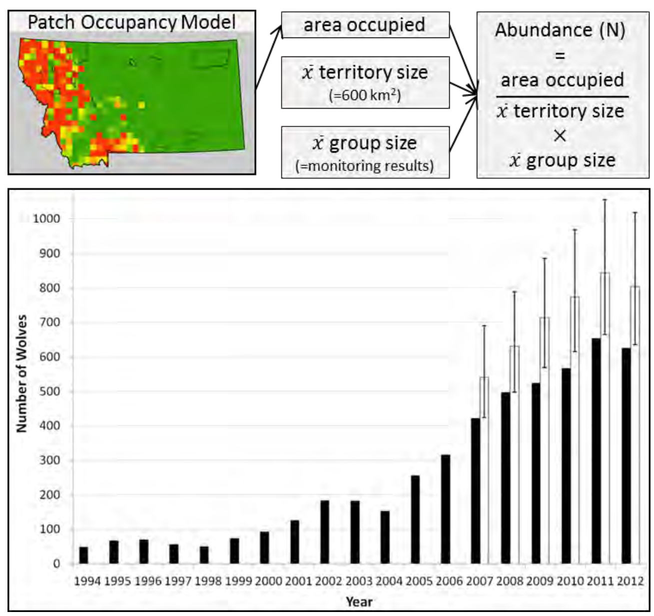

Fig. 2.1. Example of POM results (red indicates highest occupancy probability, green lowest), and methods for calculating abundance. Graphed abundance since 1994 is based on minimum counts (black bars) and POM-based estimates (white bars). (Adapted from Bradley et al. 2015.)

biasing estimates of average pack size high. Conversely, incomplete pack counts, especially for larger packs, could bias estimates of average pack size low. Harvest and depredation removals also affect social and dispersal behavior (Adams et al. 2008, Brainerd et al. 2008, Ausband 2015). Additionally, pack turnover is now greater than in populations with less human-caused mortality.

Development of reliable methods to estimate territory size, territory overlap, and pack size is critical for accurate estimates of abundance. One means for developing models to estimate territories and pack sizes is an empirical modeling approach. This approach generally involves measuring and attempting to discern patterns in territory and pack size dynamics (e.g., Rich et al. 2012). Empirical models do not, however, provide an understanding of causal mechanisms, i.e., the underlying processes that shape the system and patterns we observe, such as processes driving decisions carnivores make about where to settle and whether to stay in or leave a social group. Ignoring causal mechanisms may yield models that do not suitably predict conditions beyond the spatiotemporal scale for which they were developed (Mitchell and Powell 2002). Empirical models may also require extensive continued monitoring and data collection to provide sufficient data for predictions.

An alternative method to empirical modeling is a mechanistic modeling approach. Such an approach involves developing theoretical models that capture the hypothesized causal mechanisms structuring the system (Mitchell & Powell 2004, 2012). Mechanistic models may take the form of individual-based models (IBMs, also known as agent-based models). Although often challenging to develop, IBMs provide an ideal means for understanding the mechanisms driving territorial behavior. Consistent with the role of individuals in natural selection (Darwin 1859), IBMs are bottom-up whereby population-level behaviors and patterns emerge from the interaction of individuals with one-another and their environment (Grimm and Railsback 2005, Grimm et al. 2005, DeAngelis and Grimm 2014). IBMs therefore differ strongly from traditional population models that rely on differential equations and impose top-down population parameters (e.g., birth rate; DeAngelis and Grimm 2014). As a result, IBMs are less abstract and easier to conceptualize. Once designed, IBMs offer “virtual laboratories” for investigating how bottom-up influences of individuals give rise to complex organization of the larger system (Grimm et al. 2005). Predictions from these models can be compared to actual behaviors of animals to identify the model(s) with most support (Mitchell & Powell 2002, 2004, 2007, 2012). Resulting models are based on the likely causal mechanisms that shape the system, and thus yield reliable scientific inference and are predictive at any spatiotemporal scale. Importantly, abundant data are not required for predictions once models are developed.

2.2 Goals and General Approach

Our goal is to develop tools to estimate territory and group size of wolves to calibrate estimates of abundance of wolves from POM in Montana and Idaho. To achieve this goal, our steps will be to:

1. **Develop a suite of mechanistic territory models.** These models will capture the potential causal mechanisms we hypothesize structure territories of wolves. We will run simulations to provide general predictions of territorial behavior under each model.
2. **Identify the most predictive territory model for wolves in Montana and Idaho.** We will summarize general patterns of territories (e.g., their size and overlap) in Montana and Idaho, and compare these patterns to the general patterns predicted by our models from Step 1. We will then parameterize the models with data for Montana and Idaho and generate specific predictions of territorial behavior under each model. We will compare these predictions to actual locations of GPS-collared wolves in Montana and Idaho to test for concordance, and use multimodel inference to identify the models that most closely predict real territorial behavior. We will conduct sensitivity analyses and provide easy-to-use deliverables.
3. **Develop a suite of mechanistic group size models.** These models will capture the potential causal mechanisms we hypothesize structure social behavior of wolves. We will run simulations to provide general predictions of social behavior under each model.
4. **Identify the most predictive group size model for wolves in Montana and Idaho.** As with the territory models, we will test for concordance between model predictions and general patterns observed in real wolf packs. We will then parameterize the group size models with data for Montana and Idaho and generate specific predictions of social behavior under each model. We will compare these predictions to actual group sizes of wolves in Montana and Idaho as identified through monitoring data. We will use multimodel inference to identify the models that most closely predict actual group sizes. As with the territory models, we will conduct sensitivity analyses and provide easy-to-use deliverabes.
5. **Develop empirical models for territory and group size.** We will compare the results from steps 1 – 4 to the empirical models we develop to identify the advantages and limitations of each approach.
6. **Calibrate estimates of abundance.** We will use our models for territory and group size alongside POM to calibrate estimates of abundance of wolves in Montana and Idaho. The models will enable region-specific predictions in territories and group sizes to improve abundance estimation. These deliverables will furthermore enable managers to predict the effects of management actions by adjusting inputs, e.g., to represent increased harvest pressure to predict how territories and pack sizes will change under different harvest levels.

2.3 Progress

Step 1 is complete, fulfilling our first deliverable for Project 1 on target (end of 2017). We present in this report a summary of 2 IBMs from the full set created. A full manuscript is in preparation.

2.4 Methods

Developing IBMs for Step 1 comprised 3 primary components:

1. **Establish a model framework.** Before building the models, we determined the general framework for their structure based on behavioral theory.
2. **Develop a suite of mechanistic territory models.** Each model included hypothesized causal mechanisms of territorial behavior.
3. **Run simulations and summarize results.** This allowed us to make general predictions useful for comparing to patterns in empirical observations.

2.4.1 Model framework

Our objective was to model how packs select annual territories to predict such characteristics as territory size, location, and overlap to calibrate POM. Accordingly, we aimed to model territory selection to represent the sum of a pack's movements rather than the movements themselves. To model territory selection, the landscape can be represented as a continuous grid of patches which packs select to add to their territories (e.g., Fig 2.2). For each pack, the sum of patches selected is the territory, and the summary statistics of interest such measures as territory size and overlap.

We selected a mechanistic modeling framework to provide models predictive at any spatiotemporal scale and reduce future needs for monitoring wolves and collecting data. We designed the mechanistic models based on theory of how carnivores select territories. Carnivores are likely adapted to choose economic territories that maximize value, i.e., by maximizing benefits and minimizing costs of territory ownership (Darwin 1859, Brown 1964, Brown and Orians 1970, Emlen and Oring 1977, Krebs and Kacelnik 1991, Adams 2001). Like other carnivores, we also expect that wolves are adapted to defend the smallest territory possible that meets a threshold of resources for survival and reproduction (Mitchell and Powell 2004, 2007, 2012).

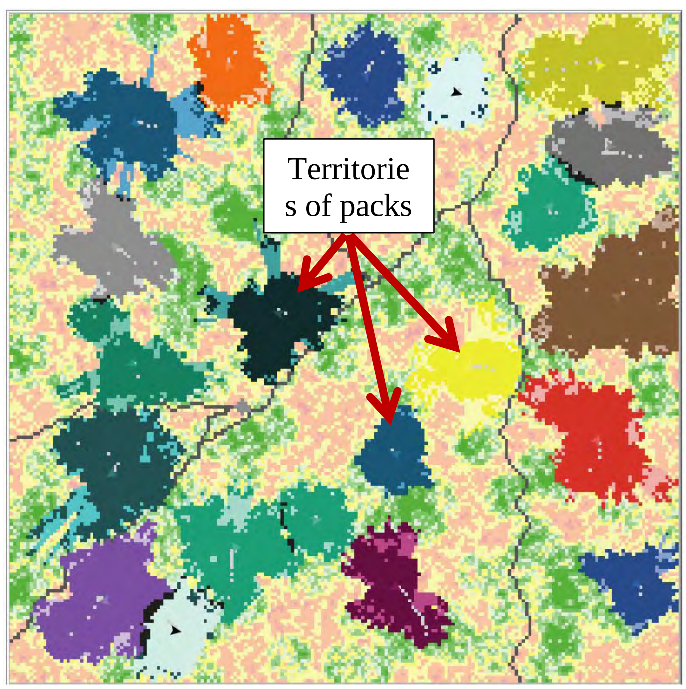

Fig. 2.2. Example of a simulated landscape where packs have formed territories. Where patches have not yet been selected, bright green patches are of high prey benefit; yellow medium, and red low. Gray lines represent major roads. Black patches indicate overlapping territories.

Building mechanistic territory models necessitated developing a set of hypotheses about which benefits and costs of territorial behavior are likely most fundamental to wolves. Conceivably, numerous benefits and costs could affect how patches are valued during territory selection. After extensive literature searches and consideration, we hypothesized that the causal mechanisms of territorial behavior include the benefits of prey and costs of travel, competition, and humans (Brown & Orians 1970; Adams 2001; Mitchell & Powell 2004, 2007, 2012). Food resources are required for all animals, and black bears (*Ursus americanus*) were shown to structure home ranges optimally with respect to the spatial distribution of food resources (Mitchell & Powell 2004, 2007, 2012). Lack of travel costs would imply that territories should be limitless in size because packs would travel any distance to reach a patch. Lack of competition costs would allow territories to overlap completely. Lastly, humans are an important source of mortality for wolves; their presence likely represents a key cost to territorial behavior.

2.4.2 Mechanistic territory models

Each competing model defined a specific hypothesis for how packs value patches for territories. Our set of models included combinations of hypotheses that wolves select territories based on the benefits of prey and costs of travel, competition, and humans. The 2 models we present here (out

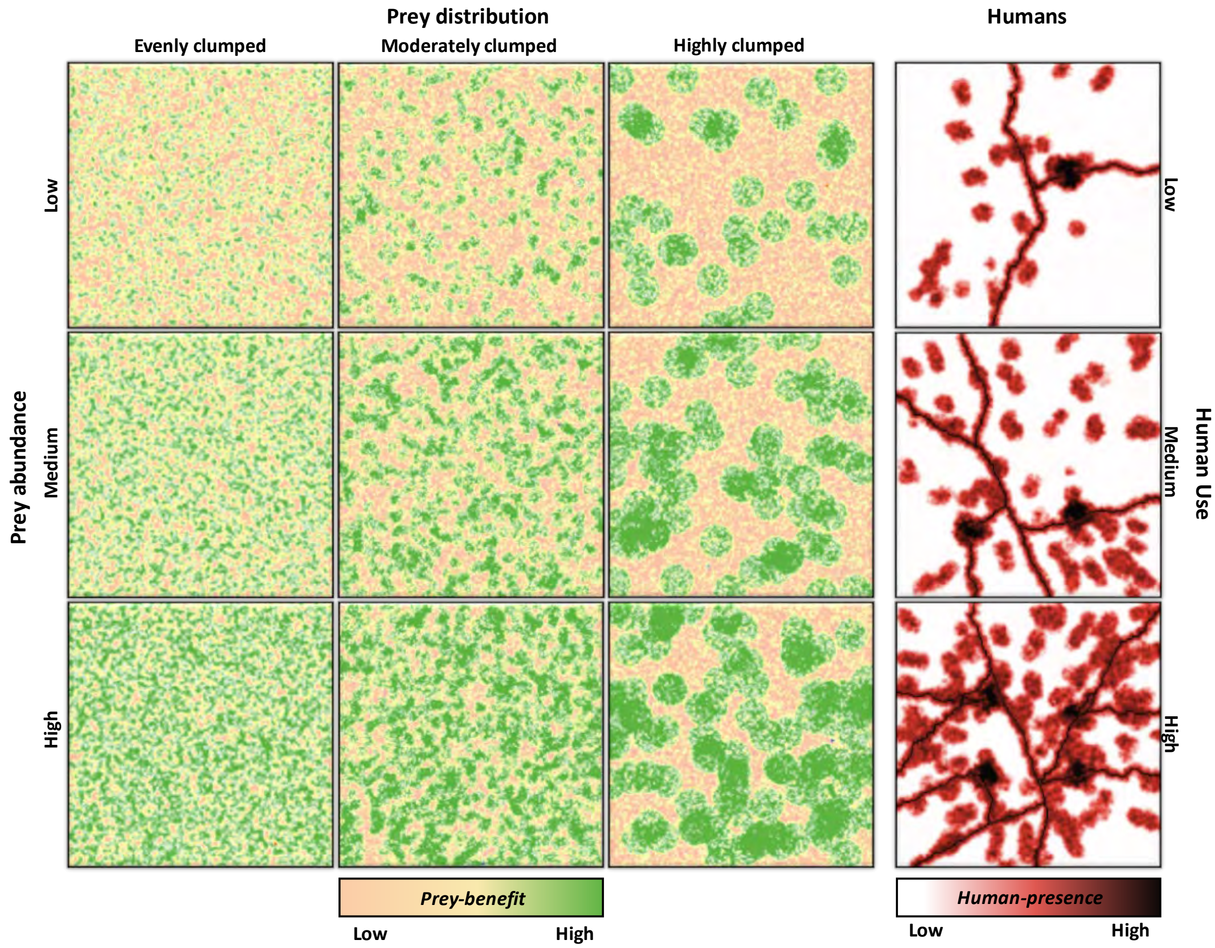

Fig. 2.3. Example simulated landscapes where prey distribution ranges from evenly to highly clumped and prey abundance ranges from low to high. Human use also ranges from low to high. Landscapes are 200 × 200 patches in size, and no 2 landscapes are exactly alike. Patches were technically scale-less at this stage. In Step 2 they will be set to represent actual spatial extents (e.g., 1, 5, or 10 km^2) based on the resolution of available data.

of our larger subset) hypothesized that wolves select patches based on benefits of prey and A) costs of travel and competition, or B) costs of travel, competition, and humans. Model B differed by including cost of humans; we hypothesized this cost may have changed post-delisting with implementation of harvest. These models will allow us to investigate this possibility in Step 2.

We designed and tested the models in the program NetLogo (Wilensky 1999). The landscape was represented as a grid of 200 × 200 patches on which packs formed territories. Each patch was associated with a benefit of prey and costs of travel, competition, and humans. Our goal at this stage was to predict how territories would vary under different scenarios. Accordingly, within any given simulation, the landscape contained a particular prey distribution (evenly to highly clumped), prey abundance (low to high), and level of human use (low to high; Fig. 2.3). The simulations also enabled exploring how wolves would structure territories if they perceived competition and humans to have various levels of costs. Accordingly, we set the costs of competition and humans between low and high for any given simulation.

Following behavioral theory, packs acquired patches for annual territories as economically as possible (Fig. 2.4). One pack colonized the landscape at a time. The pack selected patches for its territory in order of value. Patch values were the benefit of prey in a patch discounted by the costs associated with the patch (competition and travel for Model A, and competition, travel, and humans in Model B). A simulation continued until all packs formed territories and there were insufficient resources to enable more packs to colonize.

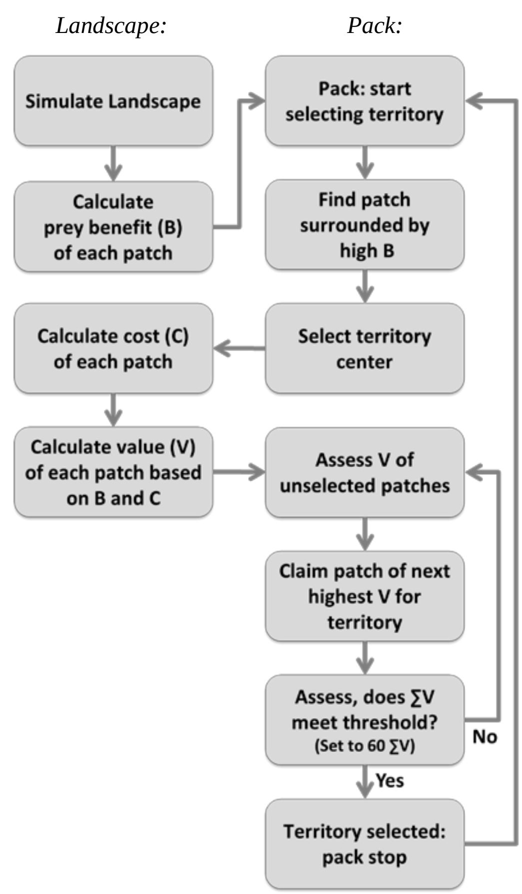

Fig. 2.4. Structure of territory simulations. A pack selects a territory by seeking patches that maximize benefits and minimize costs. It stops once it has met a threshold for survival and reproduction. The next pack then begins.

2.4.3 Simulations

To learn about our models, we completed simulations and collected data on the results, e.g., each pack's territory size and overlap. We ran 25 simulations for each combination of prey distribution, prey abundance, human use, cost of competition, and cost of humans. This yielded 675 simulations for Model A and 8100 for Model B (this higher value reflected the many combinations of human use and cost of humans).

We used program R (R Core Team 2014) to summarize results. Summaries included territory size (number of patches), territory overlap (percentage of territory patches shared with another pack), human avoidance (mean cost of humans in each patch in the territory minus the mean cost of humans in the landscape), and numbers of territories. We calculated mean results over each prey distribution, prey abundance, human use, colonization order, cost of competition, cost of humans, and model.

2.5 Results

Our simulations predicted patterns related to territory size, territory overlap, avoidance of humans, and number of territories, as follows.

2.5.1 Territory size

Territory size varied by prey distribution, prey abundance, and model (Fig. 2.5). Territories were larger in areas of low prey abundance and where prey were evenly clumped. If wolves ignored humans (Model A), territory size varied less and generally was smaller at comparable prey distributions and abundances than if wolves viewed humans as a cost (Model B). For highly clumped prey, however, territories were larger when wolves ignored human costs.

Territory size also varied somewhat with human use under Model B (Fig. 2.6). As human use increased from low to high, mean territory size increased when prey were evenly or moderately clumped, and decreased when prey were highly clumped.

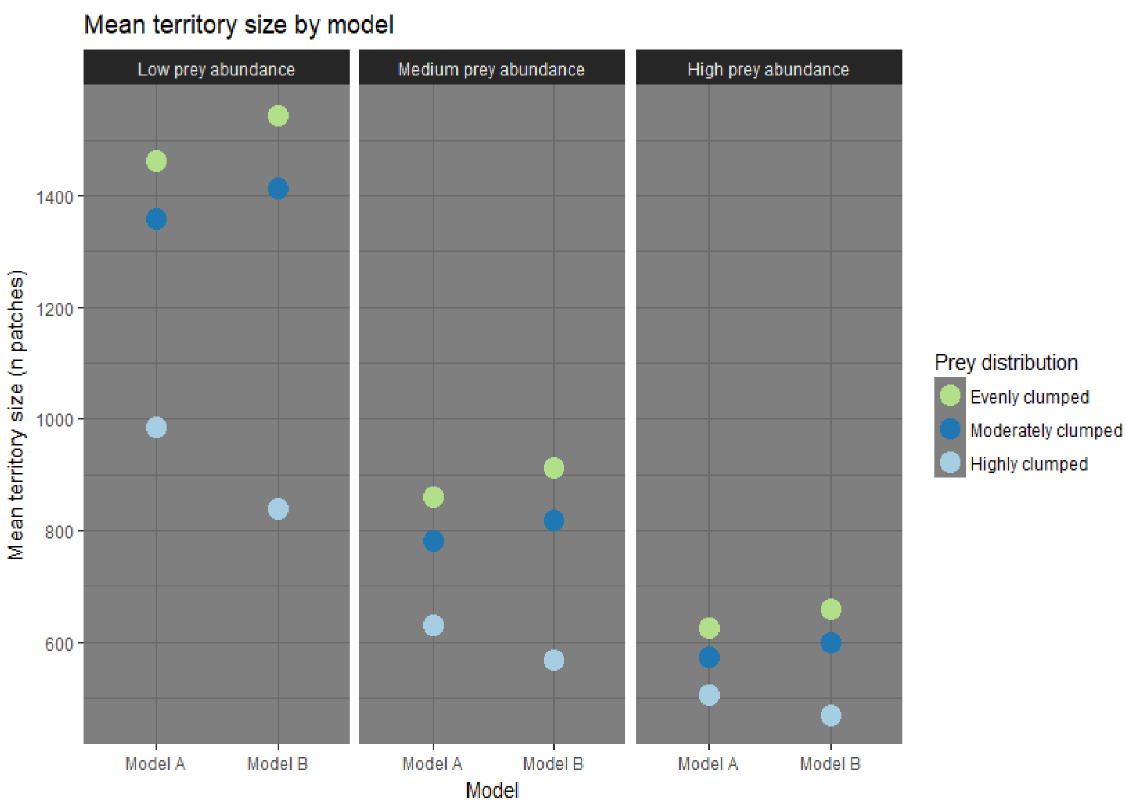

Fig. 2.5. Mean territory size decreased as prey became more clumped and as prey abundance increased. Territory sizes were larger for Model B (which includes cost of humans) except where prey were highly clumped.

Mean territory size varied by colonization order (Fig. 2.7). Later colonizers established larger territories. Where prey were highly clumped, earlier colonizers had among the smallest territories observed and later colonizers the largest. This pattern was strongest for low prey abundance.

2.5.2 Territory overlap

Mean overlap among territories was greater where prey were highly clumped and at high abundance (Fig. 2.8). Model A predicted greater overlap than Model B at comparable prey distributions and abundances, and predicted more overlap where prey were highly clumped. Mean overlap among territories depended on cost of competition (Fig. 2.9). Overlap quickly dropped to 0% as cost of competition increased.

2.5.3 Additional responses to humans

In addition to responses to humans noted above, responses to humans were measured as degree of human avoidance. Mean human avoidance varied by cost of humans and level of human use (Fig. 2.10). Because packs ignored cost of humans in Model A, they exhibited no avoidance. Under Model B, avoidance was greater when cost of humans was higher. As cost of humans increased from low to high, avoidance increased most drastically for high levels of human use.

2.5.4 Number of Territories

Numbers of territories varied by prey distribution, prey abundance, and model (Fig. 2.7). Territories were least numerous where prey abundance was low. More packs formed territories where prey were highly clumped. Fewer formed when packs considered human costs (Model B).

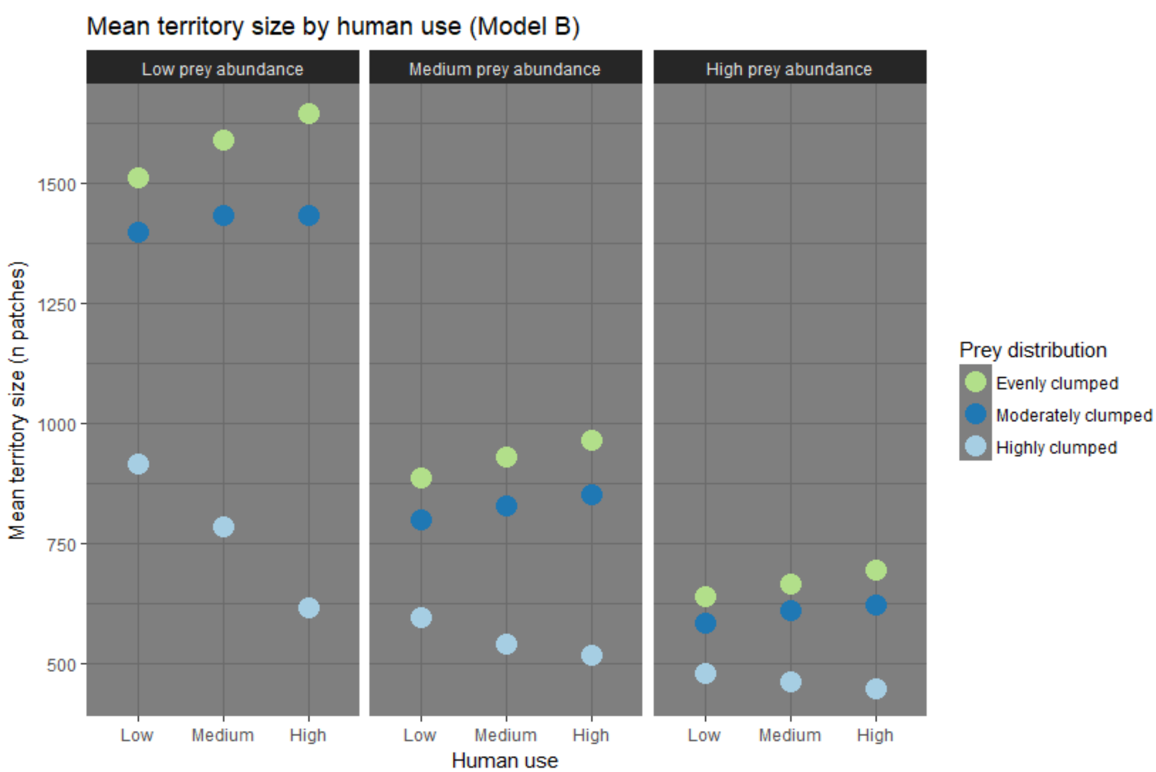

Fig. 2.6. Mean territory size increased or decreased with higher levels of human use, depending on prey distribution.

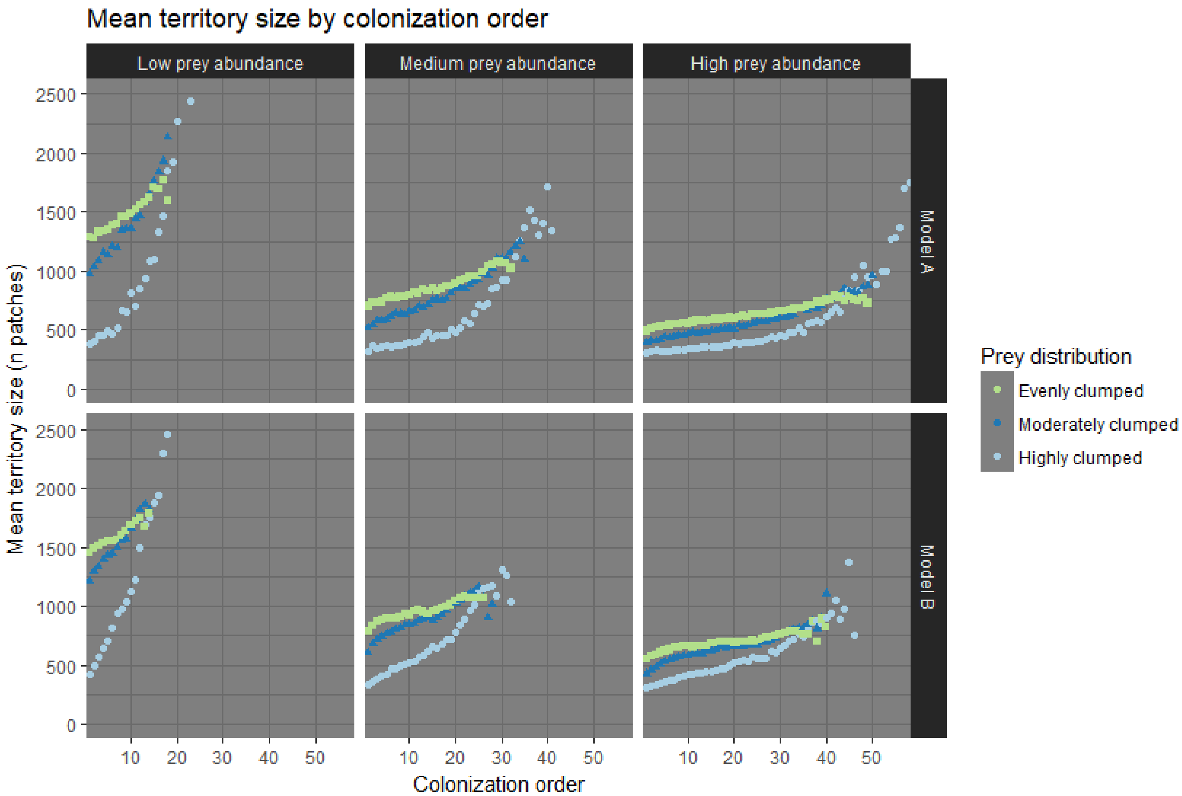

Fig. 2.7. Mean territory size varied by colonization order (e.g., 1 = 1st pack to select a territory). Late colonizers established larger territories, particularly where prey were highly clumped and at low abundance. Results also provided mean # of packs. Fewer packs formed territories on landscapes of lower prey abundances, and when they factored in human costs (Model B).

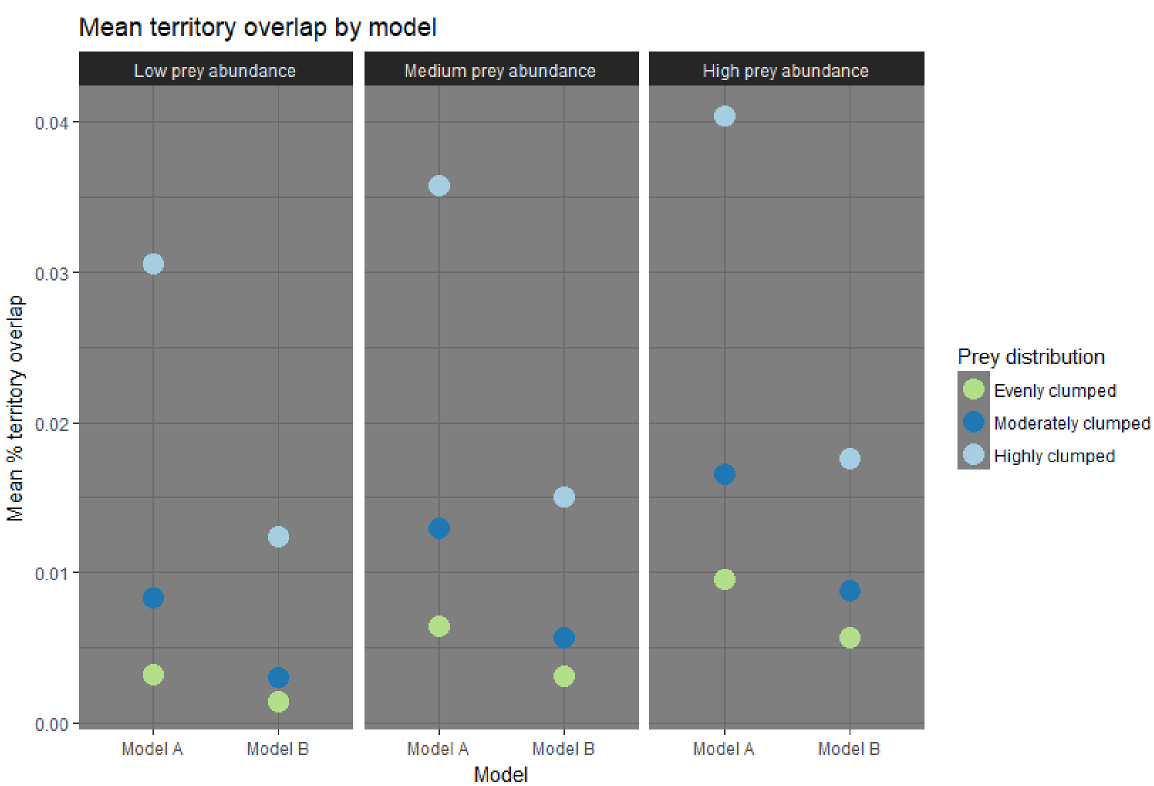

Fig. 2.8. Mean territory overlap was greatest where prey were highly clumped. Model A had a wider range of overlap across prey distributions and consistently greater overlap than Model B (which includes costs of humans).

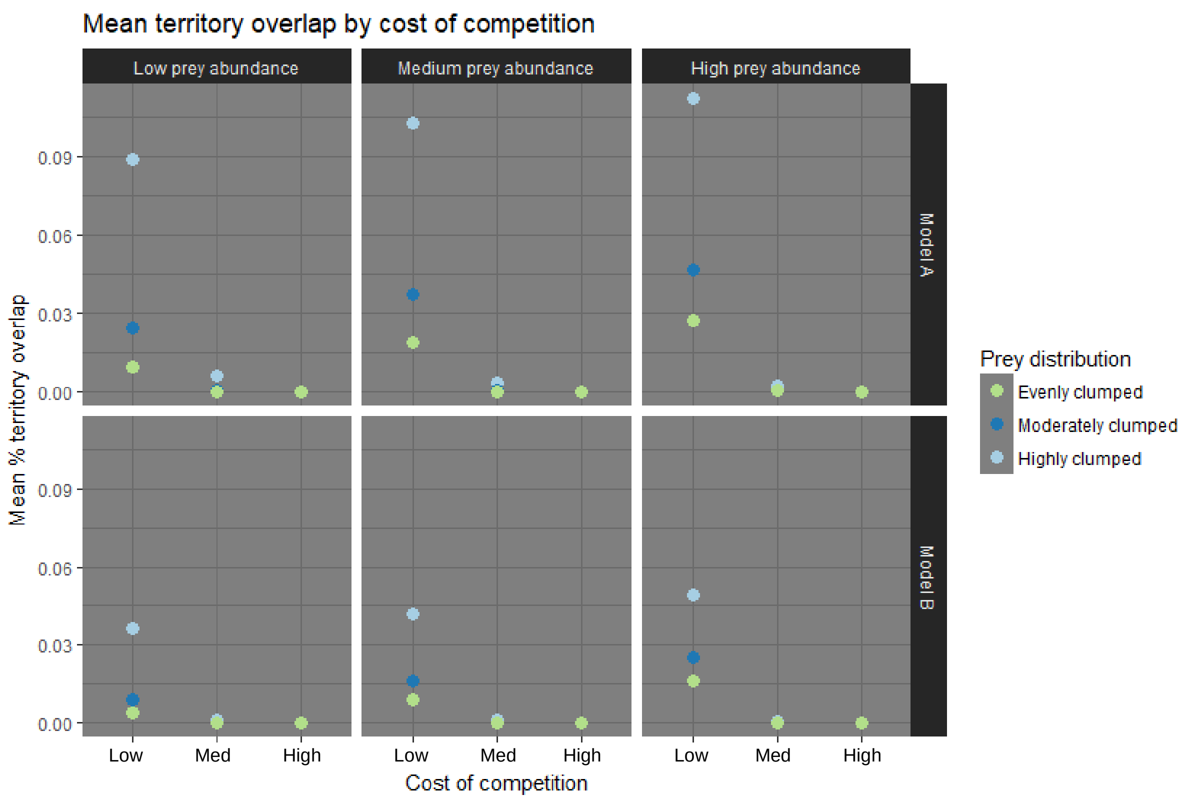

Fig. 2.9. Mean territory overlap decreased as cost of competition increased, and varied by model and prey distribution.

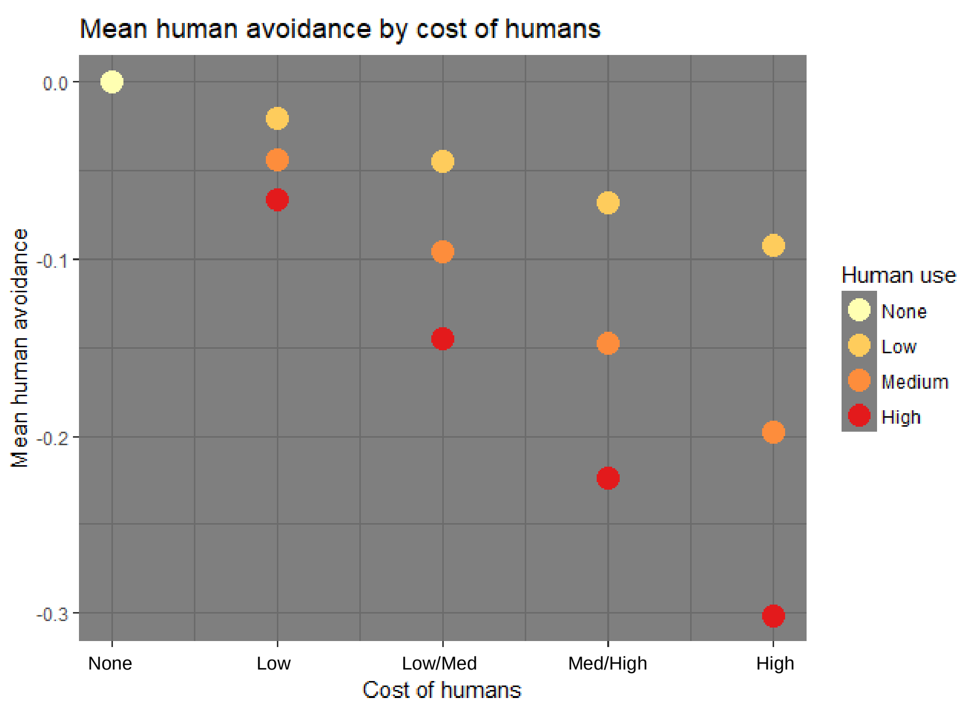

Fig. 2.10. Mean human avoidance increased with increasing cost of humans and human use (negative values indicate greater avoidance). Human use of "none" indicated 0 costs associated with human use (e.g., Model A).

2.6 Discussion

A primary deliverable for this project is a suite of territory models that will be useful for calibrating POM. We have completed our suite of territory models and Step 1 of this project on target with the project timeline. The models predict and account for how territory size and overlap may vary across Montana and Idaho. Such predictions will be critical for calibrating POM estimates in later steps of this project. At this stage, our models allow us to make general predictions of patterns we may observe empirically; these predictions are particularly useful for Step 2. Below, we discuss how our models will help Montana and Idaho meet management needs. We outline our models' general predictions for territory size, territory overlap, responses to humans, and numbers of territories; we also discuss example applications of our models' general predictions. More details, models, and predictions will be presented in our manuscript about these models (in progress).

2.6.1 Territory size

Ability to predict territory size and its spatiotemporal variation is fundamental to calibrating POM estimates. Accordingly, our models allow us to predict territory size and account for how it may vary spatiotemporally across Montana and Idaho based on factors such as prey distribution, prey abundance, human use, and population size. POM currently relies on the assumption that average territory size is 600 km^2 statewide. Over- or under-estimating territory sizes will directly influence the number of packs predicted by POM. If territories are larger than 600 km^2, number of packs and overall abundance will be overestimated. If smaller than 600 km^2, estimates will be biased low. By accounting for variation in territory sizes rather than assuming a consistent territory size statewide, future POM estimates for number of packs and abundance of wolves will be more accurate and region-specific. Below, we discuss how prey distribution, prey abundance, human use, and population size affect predicted territory sizes.

Because distribution of prey may affect wolf territories (Fig. 2.5), our models will ensure territory sizes incorporated into POM remain calibrated across the spatially and temporally variable prey populations in Montana. The models demonstrate how prey distribution may affect territory size; assuming territory size is consistent regardless of prey distributions may thus over- and under-estimate abundance from POM in any given area. Our models predict territories to be, on average, larger in areas of Montana and Idaho where prey are more evenly clumped compared to more highly clumped. Importantly, these predictions are seasonal. Where ungulates are migratory, prey benefit of patches will shift seasonally, causing packs to adjust territories to the changing values of patches on the landscape. Once we parameterize the models with empirical data in Step 2, the simulations will account for seasonal changes in spatial distributions of ungulates. The sum of season-specific predictions will provide year-round territory predictions, which will likely be larger in areas where ungulates tend to be more migratory. As an example application of these predictions, we might expect seasonal territories to be larger in areas primarily occupied by deer (*Odocoileus* spp., e.g., northwest Montana) versus elk (*Cervus* *canadensis*, e.g., southwest Montana), because deer tend to be more evenly spaced than large gregarious elk herds. Across the year, however, packs in southwest Montana may have larger territories if they respond to long distance elk and deer migrations. E.g., elk herds in the Yellowstone region may migrate 40 – 60 km (Nelson et al. 2012, Middleton et al. 2013), and mule deer (*O. hemionus*) may migrate 20 – 158 km (Sawyer et al. 2005). In contrast, in the rugged terrain of northwest Montana, white-tailed deer (*O. virginianus*) comprise the bulk of the ungulate population and generally exhibit shorter-distance elevational migrations. We would thus expect a more consistent prey distribution across seasons in northwest Montana. We expect that, after accounting for shifting prey availability, annual territories of wolves in northwest Montana will be smaller than those in southwest Montana.

Given that abundance of prey may also affect wolf territories (Fig. 2.5), our models will ensure territory sizes incorporated into POM remain calibrated across variable abundance of prey, which will further increase accuracy of POM estimates. The models demonstrate how territory size may vary based on prey abundance, e.g., territory sizes may be much larger in areas of low prey abundance compared to areas of high prey abundance. Accordingly, POM's current assumption of a consistent territory size statewide may be overestimating number of packs in areas of low prey abundance, or underestimating number of packs in areas of high prey abundance. As an example application of this prediction, we might expect territory sizes to be larger in FWP Region 5 than Region 3 where the ungulate populations differ by two-fold (~78,000 deer and elk in Region 5 versus ~146,000 in Region 3; fwp.mt.gov, accessed 2 Feb 2018). This may lead POM estimates in Region 5 to be biased high, and, conversely, estimates in Region 3 to be biased low.

Additionally, because human use may affect wolf territories (Fig. 2.6), our models will ensure territory sizes incorporated into POM remain calibrated across the spatially and temporally variable levels of human use in Montana. Our models demonstrate how territory size may vary across Montana and Idaho based on human use of the landscape. Specifically, when prey distribution is evenly or moderately clumped, Model B predicts slightly larger territories in areas with higher human use compared to areas of lower human use; conversely, where prey are highly clumped the model predicts the opposite (i.e., smaller territory sizes where human use is higher). As an example application of these predictions, when comparing territories in areas of Montana with high human use (e.g., close to cities) to areas of low human use (e.g., designated wilderness), we may expect to observe, on average, slightly larger territories where prey are evenly or moderately clumped, and slightly smaller territories where prey are highly clumped.

In Step 2, we will compare general predictions from each model to empirical patterns to ascertain model usefulness across spatiotemporal scales; Model B's predictions for territory sizes will be particularly informative. We hypothesized that wolves will associate humans with higher costs post-delisting and with implementation of harvest. If our hypothesis is supported and Model B suitably captures this behavior, post-delisting we may observe: a) a greater range in territory sizes; b) an increased mean territory size where prey distributions are evenly or moderately clumped; and c) a decreased mean territory size where prey are highly clumped (Fig. 2.5). We also hypothesized that wolves will associate humans with higher costs outside of protected areas. Accordingly, we might also expect to observe these patterns outside of Yellowstone National Park (YNP) compared to within the park.

Because wolf population size may also affect wolf territories (Fig. 2.7), our models will ensure territory sizes incorporated into POM remain calibrated across the spatially and temporally variable wolf populations in Montana. The models predict that the first packs to claim territories in an area may have smaller territories than their counterparts that colonize later. Average territory size may gradually increase as more packs form territories. Variation in territory sizes may similarly increase. Our models predict this pattern may be most noticeable in areas with highly clumped prey; where there are already many other packs, the newest packs may have among the largest territories observed. As an example application of this prediction, territories occupied for the longest in northwest Montana (e.g., some of those in the North Fork) may be among the smallest observed in that region. The same may be true for early packs in YNP. Furthermore, given the clumped nature of prey resources in YNP, the newest packs may, on average, have among the largest territories observed in Montana (if new packs do not simply usurp and maintain an old pack's territory).

2.6.2 Territory overlap

Ability to predict territory overlap and its spatiotemporal variation is similarly critical for calibrating estimates from POM. As with territory size, our models allow us to predict and account for how territory overlap may vary spatiotemporally across Montana and Idaho. POM currently assumes overlap among territories is minimal and at consistent levels statewide. Over- or under-predicting overlap among territories will directly influence accuracy in the estimated numbers of packs from POM. I.e., where overlap among territories is greater than currently assumed, abundance may be underestimated, and where overlap is less than currently assumed, abundance may be overestimated.

Because territory overlap may be affected by the distribution and abundance of prey and level of human use (Fig. 2.8), our models will ensure territory overlap incorporated into POM remain calibrated across the spatially and temporally variable prey populations and levels of human use in Montana. Our models predict that territory overlap may be highest in areas where prey are more highly clumped and of higher abundance. Territory overlap is also predicted to be lower under Model B, demonstrating that if wolves perceive humans to be a cost to territory ownership, overlap may be lower. As an example application of these predictions, we might expect overlap to be greater in southwest Montana due to a highly clumped elk population (i.e., compared to deer, see above) and high abundance of ungulates. Additionally, if there is support for our hypothesis that wolves perceive humans as more costly post-delisting, we also may expect to see less overlap among territories today than pre-harvest.

We will further refine the predictive capacity of our models in Step 2 by investigating how wolves perceive the cost of competition; this will further calibrate predictions of territory overlap to increase accuracy of POM estimates. Our models demonstrate how overlap among territories depends on how wolves perceive cost of competition (Fig. 2.9). After parameterizing our models with empirical data in Step 2, we will determine which level of costs yields predictions that most closely match wolf territories. Real packs will therefore reveal the relative costs of competition compared to other benefits and costs of territorial behavior.

2.6.3 Additional responses to humans

Ability to predict how wolves will vary territorial behavior in response to human influences is useful in several ways for calibrating estimates from POM. As discussed above, our models allow us to account for how territory size and overlap may vary spatiotemporally across Montana and Idaho in response to humans, and this will directly calibrate POM. Two additional uses merit further discussion. First, the models predict how wolves may select territories to avoid humans. These predictions will be useful towards identifying the most appropriate models for calibrating POM. Secondly, ability to predict responses to human influences means our models will be useful for predicting the effects of management actions. We address these two uses below.

In Step 2, we will identify the most appropriate model for each area of Montana and Idaho to calibrate POM predictions. The degree to which territories avoid humans will be particularly useful for identifying which models better capture territorial behavior in each area (Fig. 2.10). The models demonstrate that if wolves perceive humans as a cost to territory ownership (Model B), territories will show avoidance of humans, otherwise they will show no response (Model A). Additionally, where human use is higher, Model B predicts that territories will be selected in areas that better minimize exposure to people. Where these predictions match empirical observations, Model B will be the more appropriate model for calibrating POM; elsewhere, Model A may be the more appropriate model. For example, Model A may suitably predict territories of wolves within YNP where cost of humans may be less important, whereas Model B may better predict territories in more urban areas of Montana.

Also in Step 2, we will refine the predictive capacity of our models by investigating how wolves perceive the cost of humans; this will further calibrate model predictions to increase accuracy of POM estimates. Our models predict that avoidance of humans will be stronger if wolves associate humans with higher costs (Fig. 2.10). Once we parameterize models with empirical data and compare predictions of human avoidance to empirical observations, real packs will reveal the relative costs of humans compared to other benefits and costs of territorial behavior.

Our models will also be useful for predicting the effects of management actions. This will directly assist management decision-making and integrate well with the adaptive harvest management component of Project 2. E.g., managers will be able to adjust model components to understand how various levels of human pressure (e.g., to represent altered hunting pressure) will affect human avoidance, territory sizes, etc. Managers will also be able to predict how the removal of any given pack (i.e., through depredation removals) may affect other packs.

2.6.4 Number of territories

Though not an original deliverable, ability to predict numbers of territories and how this varies spatiotemporally can also be useful within the POM framework. Our models predict how number of territories may vary by prey distribution, prey abundance, and human use. We could use predictions for numbers of territories in two ways. First, we could incorporate these predictions within POM to calibrate estimates of colonization and resulting abundance; e.g., new colonization may be less likely in areas near predicted capacity. Secondly, we could compare our models' predictions to number of packs estimated by POM as an indicator of accuracy in POM predictions.

Given these potential uses, our models' ability to predict number of territories may be useful for POM. Our models predict slightly fewer packs in areas with evenly dispersed prey, and far fewer packs in areas with low prey abundance (Fig. 2.7). Additionally, our models predict somewhat fewer packs under Model B, if wolves perceive humans to be a cost of territory ownership. As an example application of these predictions, we may expect fewer packs in FWP Region 5 than in Region 3 where prey abundance differs two-fold. We might also expect to see fewer packs post-delisting or outside of protected areas, if wolves associate humans with higher costs than they did pre-harvest.

2.6.5 Ongoing work

Our next step will fulfill the final territory model deliverable (due late 2019) by identifying the most predictive models from the full suite of models we have developed. We are currently preparing to formally summarize general patterns of observed territories in Montana and Idaho for Step 2. General concordance between empirical observations and model predictions (e.g., including those discussed above) will indicate that the models adequately capture mechanisms of territorial behavior. We are also preparing to parameterize the models with empirical data. Running simulations with empirical data will allow us to generate specific predictions of territorial behavior for wolves in Montana and Idaho. We will compare these predictions to territories of GPS-collared wolves to investigate which models most closely predict territorial behavior of wolves in Montana and Idaho.

Our final territory models will provide spatially-explict predictions of territory size and overlap to calibrate POM, as discussed above. Furthermore, upon completing the territory models and parameterizing them with empirical data, they will also be useful for predicting locations of territories. We can use this feature, for example, to further design a finely detailed, spatially-explicit grid for POM to replace the current 600 km^2 grid and further increase accuracy of abundance estimates. We can also use this feature to predict locations of future territories (e.g., in currently-unpopulated areas of central Montana), or the effects of removals of packs (e.g., through depredation removals).

After identifying the best models, we will determine sensitivity to model inputs and level of data required for future use. This will demonstrate model robustness and the minimum data that will be required in Montana and Idaho to calculate accurate estimates of abundance in POM. Some model components will largely arise from the model itself (i.e., competition) or be easily measured using existing, widely-available data (i.e., travel costs that are based on Euclidean distance). Other inputs (i.e., prey and humans) will use basic sub-models that we will design to require existing data and little updating. More details will follow in subsequent manuscripts and reports.

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2. WOLF-LIVESTOCK CONFLICT AND THE EFFECTS OF WOLF MANAGEMENT

Investigators: Nick DeCesare, Liz Bradley, Justin Gude, Nathan Lance, Kent Laudon, Abigail Nelson, Mike Ross, Ty Smucker, Bob Inman (Montana Fish, Wildlife and Parks) and Seth Wilson (Montana Livestock Loss Board, Northern Rockies Conservation Cooperative).

Status: Published in Journal of Wildlife Management in early 2018

ABSTRACT: Wolf (Canis lupus) depredations of livestock are a ubiquitous source of conflict in every country where wolves and livestock overlap. We studied the spatial and temporal variation of wolf depredations of livestock in Montana during 2005–2015, including evaluations of targeted control efforts and public harvest as potential means to reduce depredations. During this time we collected spatial data for all confirmed wolf livestock depredations, tallied the annual number of depredation events within hunting districts, and collected data for variables potentially predictive of depredation events. We decomposed variation in depredation data into 2 distinct components: the binary presence or absence of depredation events in each district-year, and the count of depredation events in district-years with ≥1 event. We found that presence-absence
of depredations increased with wolf presence and wolf density, increased with livestock density, were highest at intermediate proportionate areas of agricultural land, and were a recurrent phenomenon such that districts with depredations the previous year were more likely to continue having them. Targeted removal, but not public harvest, significantly reduced the recurrent presence of depredations. The number of conflicts in district-years with ≥1 depredation event was positively correlated with wolf density, cattle density, intermediate proportionate areas of forested land, and the number of events during the previous year. Public harvest reduced the counts of depredation events in areas where conflict reoccurred, though with a modest predicted effect size of 0.22 fewer depredations/district-year, or 5.7 fewer depredation events statewide/year (8% of the annual average). Minimizing livestock losses is a top priority for wolf management. These results shed light on the broad-scale patterns behind chronic problems and the effectiveness of wolf management practices in addressing them.

<u>3. EVALUATING CARNIVORE HARVEST AS A TOOL FOR INCREASING ELK CALF SURVIVAL AND RECRUITMENT</u>

<u>Investigators</u>: Kelly Proffitt, Benjamin Jimenez, Rebecca Mowry, Justin Gude, and Mike Thompson (Montana Fish, Wildlife & Parks), Bob Garrott, Jay Rotella, Terrill Patterson, and Mike Forzely (Montana State University)

Status: In Progress

The detailed annual report for this project can be downloaded at http://fwp.mt.gov/fwpDoc.html?id=84911.

For the 2017-2018 season of this study, the primary objectives were:

1. Complete the first year of elk calf survival monitoring in the south Bitterroot area and initiate the second year of elk calf survival monitoring in the south Bitterroot area.
2. Estimate the 2016-2017 mountain lion population size in the south Bitterroot Valley and initiate the winter 2017-2018 mountain lion population estimation fieldwork in the upper Clark Fork watershed.
3. Evaluate the effects of wolf harvest management regulations on wolf harvest and population density.

Elk calf survival and cause-specific mortality

The overall summer survival rate for elk calves in 2016 was 0.58 (95% CI = 0.46 - 0.68). Summer survival of calves tagged in the West Fork was 0.63 (95% CI = 0.40 – 0.80), and summer survival of tagged calves in the East Fork was 0.54 (95% CI = 0.40 – 0.66). In 2016, the overall winter survival rate was 0.74 (95% CI = 0.62 – 0.82). As with summer, winter survival was slightly higher in the West Fork (0.83, 95% CI = 0.66 – 0.92) than in the East Fork (0.68, 95% CI = 0.51 – 0.80), but confidence intervals of the two survival estimates broadly overlapped. The overall 2016 yearly survival was 0.44 (95% CI = 0.33 – 0.53), and was higher in the West Fork (0.51, 95% CI = 0.32 – 0.68) than in the East Fork (0.38, 95% CI = 0.26 – 0.50). Yearly survival for calves in the 2016 cohort was similar to earlier survival estimates obtained prior to the initiation of liberalized predator harvest regulations in the study area.

In addition to monitoring elk calf survival, we investigated cause-specific calf mortality. In the 2016 cohort, morality due to unknown causes accounted for the highest proportion of cause-specific mortality (0.45), followed by mountain lion predation (0.18), and natural non-predation deaths (0.18).

In 2017, we captured 102 elk calves from 27 May to 6 June 2017. Similar to previous years, we used a combination of ground and helicopter search effort to locate calves in the East Fork, West Fork, and Big Hole Valley. Of the 102 calves, 45 were in the East Fork population, 20 were in the Big Hole Valley and part of the migratory East Fork population, and 37 were in the West Fork population. We outfitted each calf with a TW-5 VHF ear-tag radio transmitter (Biotrack

LtD., Wareham Dorset). Each transmitter was designed to detect movement and emit an increased pulse rate indicating a mortality event if no movement was detected within four hours. To increase our sample size of marked calves entering the winter monitoring period, we captured and ear-tagged 25 additional 6-month-old calves from 30 November 2017 to 2 December 2017. We captured 6-month-old calves using a combination of helicopter darting and net-gunning. We fit each calf with a radio transmitter as previously described, and recorded the sex of each calf.

As of February 12, 2018, we investigated 60 potential mortality events from the 2017 cohort of instrumented elk calves. Of the 60 investigations, we confirmed 31 elk calf mortalities. In the remaining 29 investigations we found ear tags with no evidence of a calf mortality, and therefore classified these as "unknown fate/tag loss." From date of capture to 31 October 2017, only two calf mortalities were located >24 hours after we initially detected a mortality signal. The two leading causes of known mortality were mountain lion predation and natural non-predation.

Mountain lion population estimation

To assess the effects of mountain lion harvest management on mountain lion population density, we will compare mountain lion densities in a treatment and control area before and after 4-years of increasing mountain lion harvest quotas in the treatment area. During 2012 and 2013, we estimated pre-treatment mountain lion density in portions of the area managed for mountain lion reduction (south Bitterroot study area) and the area managed for stability (Upper Clark Fork study area) in FWP Region 2. During the 2016-2017 period of this study, our objective was to collect data to estimate mountain lion abundance in the southern Bitterroot study area.

We used a spatially explicit capture-recapture model derived from the hierarchical model formulation of a spatially unstructured capture-recapture model to estimate population abundance and density. We incorporated telemetry information from collared mountain lions to improve inference on space use. Previous work in this system suggested that male mountain lions have larger home ranges than females, which has potential implications for density estimates. Our approach uses a single model to simultaneously incorporate spatial information from the organized search effort, harvested individuals, and collared individuals to estimate the density of mountain lions in the study area. Given the changes in methodology, we have generated estimates of mountain lion density for the 2012-2013 study period using just the revised code, as well as the revised code with the addition of telemetry information, to compare to previously published estimates for 2012-2013 (Table 1).

Table 1. Mountain lion population estimates and density in the southern Bitterroot study area, and broken down by hunting district.

		2012-2013		2016-2017	
		Published	Revised model	Revised model, without telemetry	Revised model, with telemetry
Southern Bitterroot Study Area	$\hat{N}$	**226**	**215 (147, 354)**	**223 (138, 377)**	**155 (106, 232)**
	$\hat{density}$	**3.8 (2.6, 6.5)**	**3.49 (2.4, 5.7)**	**3.6 (2.2, 6.1)**	**2.5 (1.7, 3.8)**
HD 250	$\hat{N}$	**82 (54, 141)**	**86 (58, 141)**	**86 (56, 150)**	**48 (32, 75)**
	$\hat{density}$	**4.5 (2.9, 7.7)**	**4.7 (3.2, 7.7)**	**4.7 (3.0, 8.2)**	**2.6 (1.7, 4.1)**
HD 270	$\hat{N}$	**79 (51, 137)**	**80 (54, 132)**	**82 (51, 141)**	**64 (48, 90)**
	$\hat{density}$	**5.2 (3.4, 9.1)**	**5.4 (3.7, 8.9)**	**5.5 (3.5, 9.6)**	**4.3 (3.2, 6.1)**

To estimate the winter 2017-2018 mountain lion population density in the Upper Clark Fork study area, we applied similar field methodologies and sampling protocols to those described previously in the south Bitterroot study area. Beginning December 3, 2017, hound handlers systematically searched designated areas and began collecting mountain lion hair, scat and muscle samples. As of February 1, 2018, a total of 107 person-days of effort has occurred and 51 samples have been collected. A total of 1 male and 5 female mountain lions have been fitted with GPS collars programmed to collect a location every 3 hours for 2 years. An additional 51 samples from harvested mountain lions in and around the study area have been collected. Field sampling is continuing through March 31, 2018.

Effects of wolf harvest management regulations on wolf harvest and population density.

Between 2008 and 2011, wolves in Montana were delisted, relisted, and then delisted again. This process resulted in a Montana wolf hunting season in 2009, no hunting season in 2010, and then wolf hunting seasons from 2011 through the present. Since FWP most recently regained wolf management authority in 2011, wolf harvest limits and hunting season dates have been liberalized, and the use of specific trapping methods has been approved. Since 2011, there are no wolf harvest limits for HD 270 or 250 areas. Harvest regulations are based on combined hunting and trapping bag limits of wolves per person. In 2012, the wolf harvest regulations limited each person to harvesting no more than 3 wolves, with no more than 1 taken during the rifle season. In 2013 until present, the wolf harvest regulations limited each person to harvesting no more than 5 wolves, with no more than 1 taken during the rifle season. All hunters and trappers are required to report all harvested wolves to FWP. We used hunter and trapper reports to track the number of wolves harvested annually from mandatory reporting records.

The annual harvest quota and reported harvest of wolves in the in the HD 270 and HD 250 area of the south Bitterroot study area during 2008–2016.

Year	HD 270 Harvest	HD 250 Harvest
2008	0	0
2009	2	3
2010	0	0
2011	5	6
2012	5	8
2013	6	4
2014	3	1
2015	2	2
2015	2	2
2016	15	4

In 2000, FWP counted a minimum of 7 wolves in the entire Bitterroot Valley, and the minimum count increased to a high of 74 in 2011. In 2011, there was a minimum of 28 wolves in the West Fork (1.95wolves/100km^2) and 8 wolves in the East Fork (0.47 wolves/100km^2) of the south Bitterroot study area.

The estimated minimum count of wolves in the HD 270 and HD 250 area of the south Bitterroot study area during 2001-2016.

Year	HD 270 Minimum count	HD 270 Minimum number per 100 km^2	HD 250 Minimum count	HD 250 Minimum number per 100 km^2
2001	2	0.12	5	0.35
2002	5	0.29	5	0.35
2003	Not available	Not available	4	0.28
2004	Not available	Not available	6	0.42
2005	Not available	Not available	11	0.77
2006	10	0.58	11	0.77
2007	17	0.99	14	0.97
2008	15	0.87	19	1.32
2009	13	0.76	24	1.67
2010	20	1.16	30	2.09
2011	8	0.47	28	1.95
2012	10	0.58	23	1.60
2013	12	0.70	16	1.11
2014	27	1.22	7	0.49
2015	19	0.87	7	0.49
2016	20	0.76	9	0.63

4. RE-EVALUATING THE BREEDING PAIRS INDEX FOR WOLVES TO ACCOUNT FOR THE EFFECTS OF HARVEST

Investigators: Mike Mitchell, Ally Keever (Montana Cooperative Wildlife Research Unit, University of Montana, Missoula MT), Kevin Podruzny, (Montana Fish, Wildlife and Parks)

Status: In Progress

INTRODUCTION

Our objective was to evaluate the effects of harvest at the pack and population level on the probability a pack contains a successful breeding pair. Specifically we wanted to know how human-caused mortality differed between the pack and population level and how harvest and control removals affected the probability a pack contained a successful breeding pair. We used data from the Montana portion of the Northern Rocky Mountain wolf population from 1986-2016 to estimate the probability a pack contained a successful breeding pair based on pack size, population growth rate the year prior, conspecific density the year prior, and human-caused mortality including harvest, control removals, and other mortalities (e.g., vehicle accidents or poaching). We hypothesized that human-caused mortality at the pack level would reduce the probability a pack contains a successful breeding pair more than at the population level because the pack is the reproductive unit in the population. We also hypothesized that control removals would have a greater effect than harvest because harvest is less targeted and more spread out therefore there is little to no effect of harvest. Alternatively, we hypothesized that harvest would have a greater effect than control removals because more packs are likely to be affected and have a reduction in recruitment via direct and indirect effects. Furthermore, based on findings by Mitchell et al. (2008), we hypothesized 1) that the probability a pack contains a successful breeding pair would increase with pack size because wolves are cooperative breeders that benefit from non-breeding helpers, 2) a negative relationship with population growth rate the year prior because in a rapidly growing population small packs should be vulnerable to loss of breeding pair status, and 3) a negative relationship with conspecific density the year prior because of density-dependent survival and reproduction.

METHODS

Breeding Pair Status

Montana Fish, Wildlife, and Parks and cooperating partners collected and compiled monitoring data of the wolf population every year since recolonization of northwest Montana. Early on, wolf packs were monitored using ground tracking for uncollared packs and aerial observations coupled with ground tracking for radiocollared packs throughout the year. Breeding was documented via observations of pack denning and composition later in the year. Monitoring methods adapted as the wolf population grew to include camera traps to document successful breeding pair status and pack size. Further, as the wolf population grew the goal of monitoring changed from trying to document every wolf, pack, and breeding pair to documenting minimum count and breeding pairs from collared packs. As such, data from later years represents a sample of the population. We excluded packs of unknown breeding pair status and, by definition of a breeding pair, packs with less than 4 wolves. Additionally, we only used data from packs that observers considered good quality counts, which became particularly important as the wolf population grew.

Population Growth Rate, Density, and Human-Caused Mortality

We used estimates of abundance from FWP's statewide wolf monitoring program to calculate density and population growth rate (λ). FWP used hunter surveys of wolf detection data in a patch occupancy model (MacKenzie et al. 2002, Rich et al. 2013, Boyd et al. 2017) to estimate area occupied by wolves, and used estimates of mean territory size and pack size to estimate abundance of wolves in that area (for full details of abundance estimation methods see (Boyd et al. 2017)). Occupancy has been successfully applied to wolves to estimate abundance throughout the northern Rocky Mountains (Rich et al. 2013, Ausband et al. 2014, Bassing 2017), and is a viable method even with heavy harvest (Bassing 2017). Estimates of abundance were not available prior to 2007, so we used the relationship between estimated abundance and minimum counts to estimate abundance prior to 2007. We calculated the percent different between the abundance estimates and minimum counts from 2007-2016. We assumed that the minimum counts from 1986-1995 were accurate and represented a census of the population, therefore the percent different between estimates and minimum counts was 0. We then fit a linear model, quadratic model, a 3rd order polynomial, and a 4th order polynomial with the percent difference as the dependent variable and time as the independent variable to account for the growing population and change in monitoring effort overtime in program R 3.2.5 (R Core Team 2017). We used the model with most support based on Akaike information criterion corrected for small sample size (AICc; Burnham and Anderson 2002), package AICcmodavg (Mazerolle 2017), to predict the percent difference between estimated abundance and minimum counts for years without abundance estimates and then used that different to calculate abundance. We then calculated density (# wolves/1000 km^2) by dividing abundance by the reported maximum area occupied by wolves from the patch occupancy model (76200 km^2) and multiplied by 1000. To calculate λ we divided abundance from the next year by the current abundance (N_{t+1}/N_t).

Human-caused mortality was broken down into harvest, control removals, and other human-caused mortalities which included vehicle or train accidents, poaching, and wolves taken under federal regulation 10(j). We used the number of reported human-caused mortalities in each category for each year and calculated the percent of the wolf population lost each year to those sources of human-caused mortality. These represent a minimum of the mortality that occurred as some wolf mortalities, primarily due to natural causes, were undocumented. At the pack level we used the number of wolves lost in each pack monitored for breeding pair status in each category and the total pack counts to calculate the percent of the pack lost to each category of human-caused mortality.

Analyses

We used generalized linear mixed-effects models with a logit link using package lme4 (Bates et al 2015) in program R 3.2.5 (R Core Team 2017) to estimate the probability a pack contained a successful breeding pair based on 11 candidate models (Table 1) representing logical combinations of our *a priori* hypotheses. We used a random effect of pack to account for a lack of independence in our data and to avoid pseudoreplication. Based on initial model results we refit the models without the random effect using generalized linear models with a logit link and tested for overdispersion in our data by estimating the overdispersion parameter ($\hat{c}$) using the Pearson chi-square divided by the residual degrees of freedom (McCullagh and Nelder 1989; Venables and Ripley 2002). We then tested for the effects of human-caused mortality at the pack and population level, density the year prior, population growth rate the year prior, and pack size on the probability a pack contained a successful breeding pair. We compared models using AICc (Burnham and Anderson 2002) using package AICcmodavg (Mazerolle 2017). We assessed model fit of the top models using the receiver operating characteristic (ROC) statistic (Hosmer and Lemeshow 2000). Finally, we tested for collinearity among covariates and excluded collinear covariates within the same model ($r > |0.55|$; Zuur et al. 2010).

RESULTS

We excluded 131 observations (8.6%) of the original dataset because of unknown breeding status. All observations from 1986-1998 had unknown breeding pair status (n=57), and 71 observations (51.4%) had unknown breeding pair status in 2016. Of the remaining 1384 observations 44% were considered good quality while 14% and 36% were considered moderate and poor quality, respectively. After excluding pack counts with unknown breeding pair status and packs of less than 4 wolves we had 477 observations of good quality pack counts and breeding pair status from 187 packs, 1999-2016. The mean observations per year was 26.5 (SD=13.01). On average, each pack had 2.6 observations (SD=2.30), with 13 observations (i.e., 13 years of good quality counts and documented breeding pair status) from 1 pack. Average pack size was 6.90 (SD=2.770), and ranged from an average pack size of 5.86 (SD=1.86) in 2000 to 8.33 (SD=1.97) in 1999.

Population Growth Rate, Density, and Human-Caused Mortality

The model with most support for the correlation between the % difference in abundance estimates and minimum counts and time was the 3rd order polynomial (Table 2; Figure 1). Using this relationship the predicted mean difference between abundance estimates and minimum counts from 1996-2006 was 13.8% (SD=6.64%), and resulted in an average of 31 (SD=31.2) more wolves than the minimum count for those years (Figure 2). Density of wolves increased over time in a logistic growth pattern similar to abundance (Figure 2), with a mean of 4.59 (SD=4.864) wolves/1000km^2 over 1986-2016. Population growth rate has varied across years with a mean growth rate of 1.19 (SD=0.389), however the variation has dampened in recent years (Figure 3A). Population growth rate has also appeared to decrease with increasing abundance, however this relationship was weak (Figure 3B).

Human-caused wolf mortality at the population level varied throughout the recovery process for wolves (Figure 4). The mean % wolves harvested during 2009, 2011-2016 was 21% (SD=6.0%), whereas mean % wolves removed for control during that time period was 9% (SD=4.2%) and mean % wolves that died from other human-caused mortality was 3% (SD=0.8%). From 1986-2008 and 2010 the average % of wolves removed for control and that died from other human-caused mortality was 11% (SD=11.9%) and 9% (SD=8.7%), respectively.

Human-caused mortality at the pack level was relatively low compared to the population for all categories. During years without harvest the % wolves removed for control and the % wolves that died from other human-caused mortality per pack was 6% (SD=12.8%) and 4% (SD=8.1%), respectively. Harvest removed an average of 14% (SD=14.2%) wolves per pack whereas control and other human-caused mortality was 3% (SD=10.1%) and 2% (SD=5.4%), respectively.

Successful Breeding Pairs

There was collinearity between density and lambda (R = -0.65) and population level harvest mortality (R = 0.73), between population level harvest and population level control removals (R = -0.64), and between pack level control removals and population level other human-caused mortality (R = 0.94), which limited their use in the same model. The variance explained by the random effect of pack in the mixed-effects models all overlapped 0 and were therefore not supported. All inference was based off the fixed-effects generalized linear models. We estimated the overdispersion parameter ($\hat{c}$) to be 1.03, suggesting the data were not overdispersed and were independent. Models with most support included pack size, population growth rate, and human-caused mortality at the population level (Table 1). Density and pack-level human-caused mortality had little support for influencing the probability a pack contained a successful breeding pair.

Pack size had a positive relationship with the probability a pack contained a successful breeding pair (Table 3). For each additional wolf in the pack, the pack was 1.67 (1.29-2.15; 95% C.L.) times as likely to contain a successful breeding pair (Figure 5). Population growth rate decreased the probability a pack contained a successful breeding pair (Figure 6), however this effect was more variable (Table 3). The effect of total human-caused mortality at the population level was positive, and for each % increase in human-caused mortality the pack was 0.24 (0.012-4.91; 95% C.L.) times as likely to contain a successful breeding pair (Figure 7). Control removals and harvest at the population level had opposite effects, with a negative effect of % control removal mortality and a positive effect of % harvest mortality on the probability the pack contains a successful breeding pair (Table 3).

When wolves were listed under the ESA, for the average pack size of wolves (mean = 7.10; SD = 2.76), the average population growth rate (mean = 1.26; SD = 0.248), and the average % human-caused mortality at the population level (mean = 0.20; SD = 0.071), the probability a pack contained a successful breeding pair was 0.71 (0.64-0.76; 95% CL). For the average pack size of wolves during the delisted period (mean = 6.71; SD = 2.77), the average population growth rate (mean = 1.05; SD = 0.138), and the average % human-caused mortality at the population level (mean = 0.32; SD = 0.048) the probability a pack contained a successful breeding pair was 0.76 (0.70-0.81; 95% CL). During the listed and delisted period with their respective population growth rates and % human-caused mortality the probability a pack of size 4 contained a successful breeding pair was 0.35 (0.27-0.44; 95% CL) and 0.46 (0.38-0.56; 95% CL), respectively.

Table 1: Model selection from 11 candidate models for the probability a pack contains a successful breeding pair including the number of parameters (K), AIC value corrected for small sample size (AICc), delta AICc (ΔAICc), model weight (Weight), the log-likelihood (LL), and the ROC statistic.

Model	**K**	**AICc**	**ΔAICc**	**Weight**	**LL**	**ROC**
Count+Lambda+PopMort	4	523.80	0.00	0.27	-257.86	0.75
Count+Lambda+PopHarvest	4	524.57	0.77	0.18	-258.24	0.75
Count+Lambda+PopMort+Count*PopMort	5	524.90	1.10	0.15	-257.39	0.75
Count+Lambda+PopControl	4	524.95	1.15	0.15	-258.43	0.75
Count+Lambda	3	526.07	2.27	0.09	-260.01	0.74
Count+Lambda+PackControl	4	527.67	3.87	0.04	-259.79	0.74
Count+Lambda+PackHarvest	4	527.68	3.88	0.04	-259.80	0.75
Count+Lambda+PackMort	4	528.07	4.27	0.03	-259.99	0.74
Count	2	528.33	4.53	0.03	-262.15	0.73
Count+Lambda+PackMort+Count*PackMort	5	530.05	6.25	0.01	-259.96	0.74
Count+Density	3	530.26	6.46	0.01	-262.10	0.74

Table 2: Model selection from 4 candidate models for the relationship between % difference in abundance estimates and minimum counts and time, including the number of parameters (K), AIC value corrected for small sample size (AICc), delta AICc (ΔAICc), model weight (Weight), and the log-likelihood (LL).

Model	**K**	**AICc**	**ΔAICc**	**Weight**	**LL**
3rd order	5	-71.55	0.00	0.80	42.92
4th order	6	-67.97	3.58	0.13	43.21
2nd order	4	-66.22	5.33	0.06	38.44
Linear	3	-62.22	9.33	0.01	34.86

Table 3: Model coefficient estimates (β) and standard errors (SE) on the logit scale for the probability a pack contains a successful breeding pair.

Coefficient	**β**	**SE**
Intercept*	-2.15	1.4
Pack size (Count)*	0.51	0.13
Lambda*	-0.56	0.62
Population-level mortality (PopMort)	3.18	1.54
Population-level harvest (PopHarvest)	2.15	1.15
Population-level control (PopControl)	-4.07	2.30
Pack-level mortality (PackMort)	0.12	0.60
Pack-level harvest (PackHarvest)	0.56	0.87
Pack-level control (PackControl)	-0.57	0.86
Density	0.0082	0.026

*These coefficients estimates and standard errors were model-average and are reported as the unconditional estimate and unconditional standard error because they appeared in multiple models

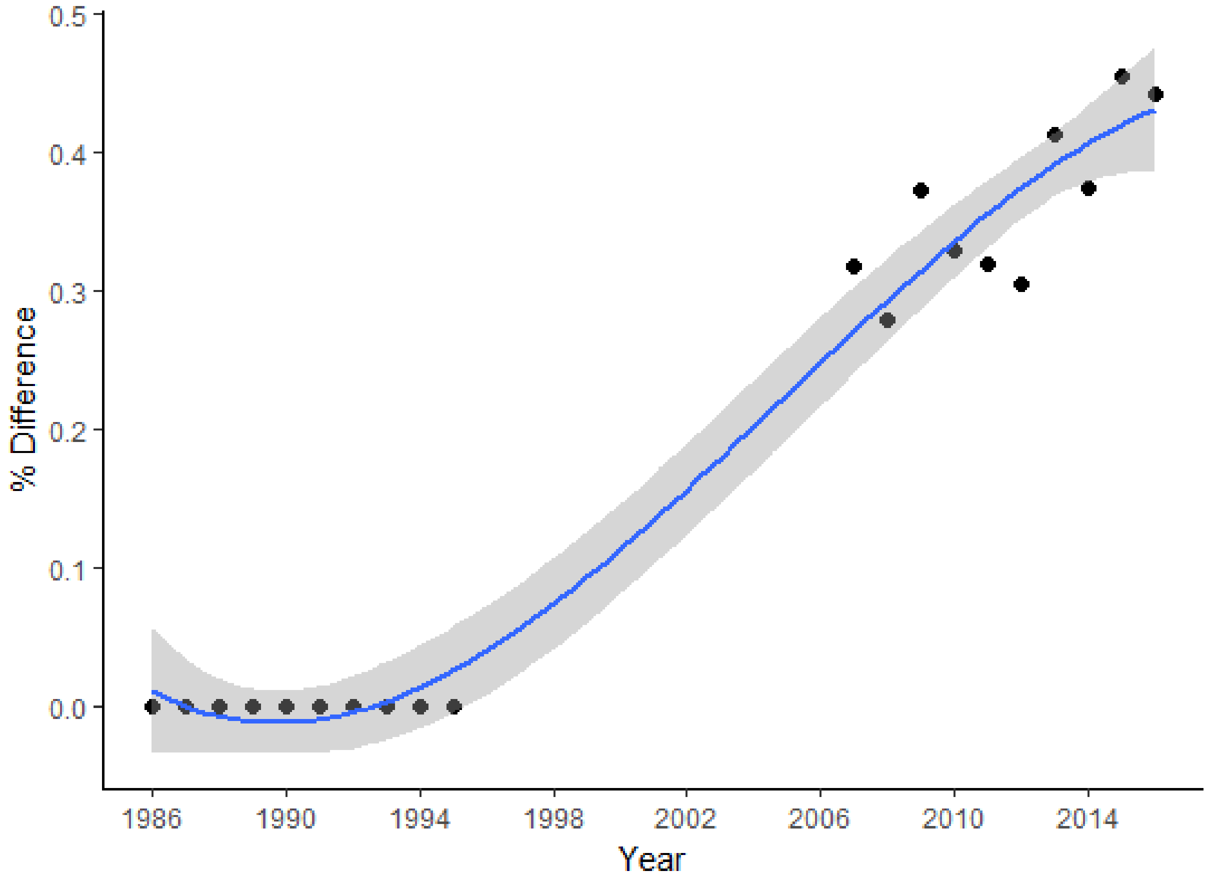


Figure 1: Predicted % difference in abundance estimates and minimum counts over time (blue line) with 95% confidence limits and the actual % difference in abundance estimates and minimum counts (black circles).

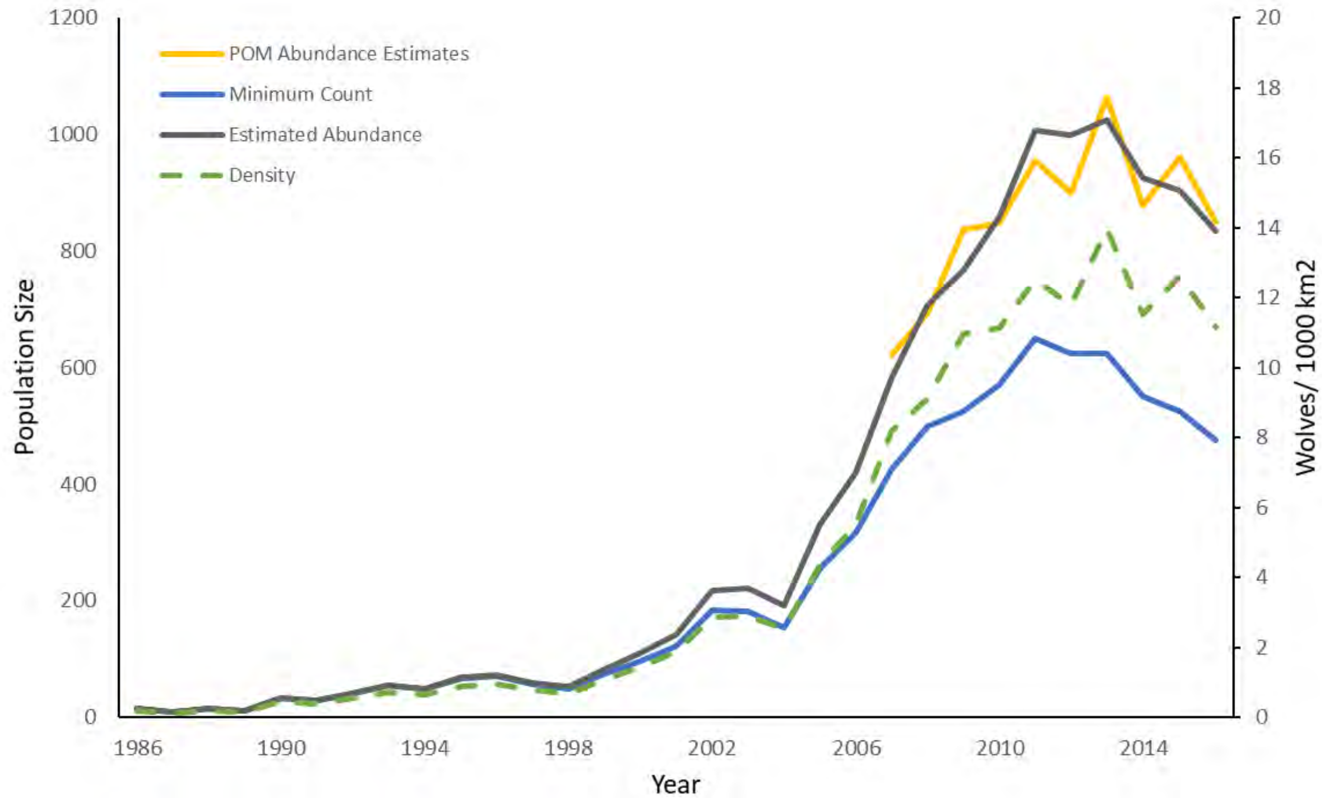
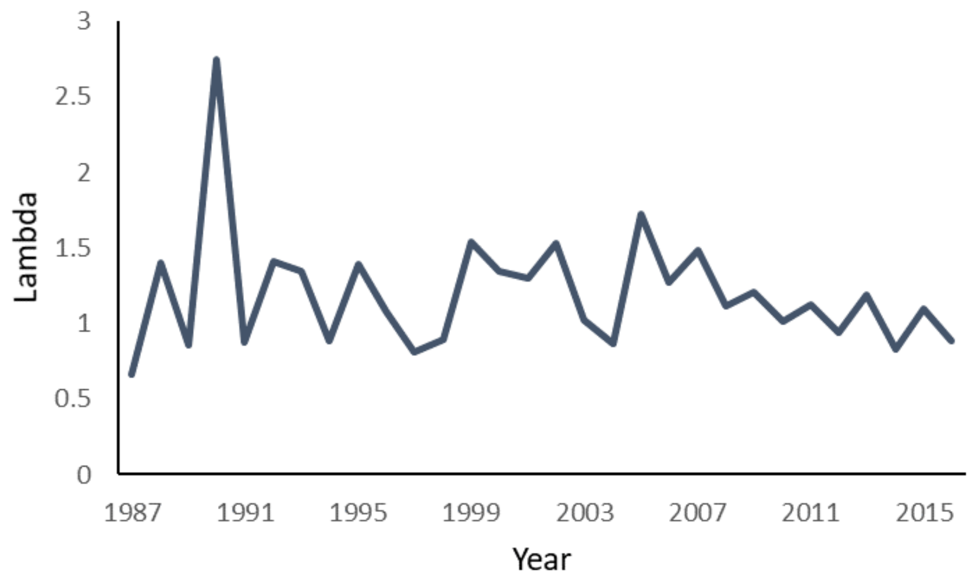


Figure 2: Abundance estimates for wolves in Montana from 1986-2016 from patch occupancy model (POM), minimum counts, and estimated abundance based off of relationship between the % difference of estimated abundance and minimum counts and time. The secondary y-axis is density of wolves.

A



B

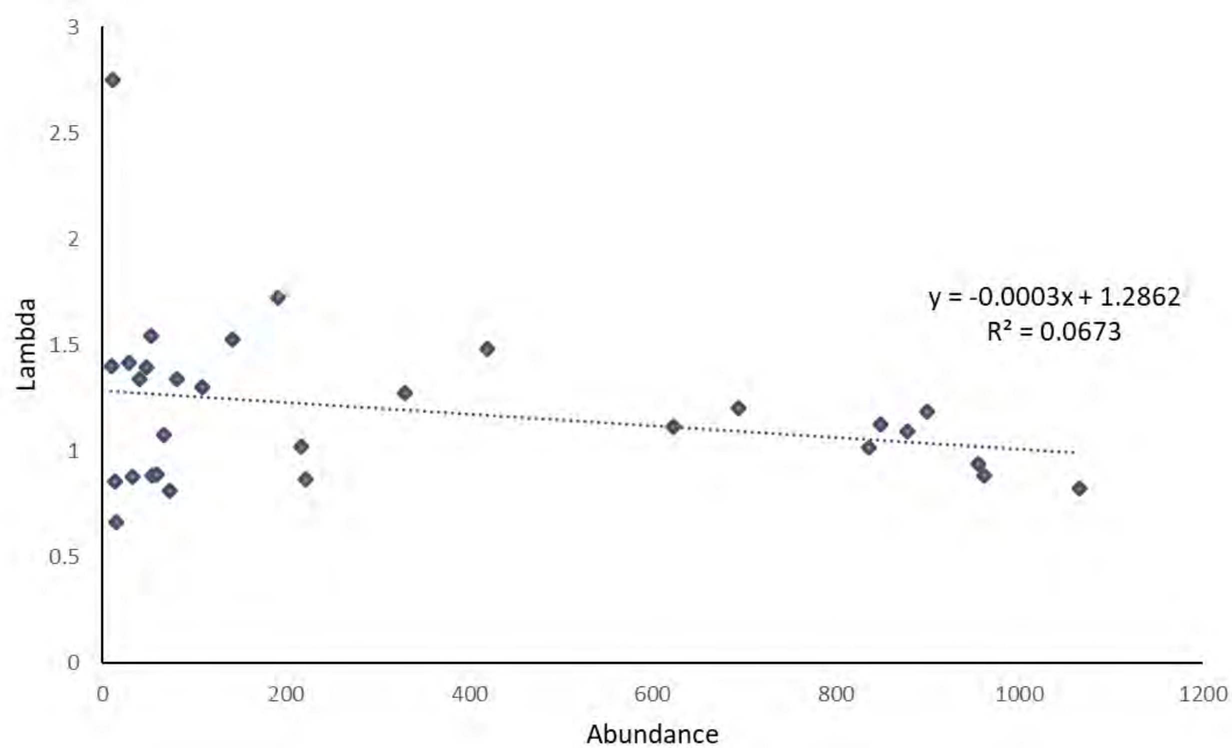


Figure 3: Population growth rate for wolves in Montana as a function of time (A) and abundance (B).

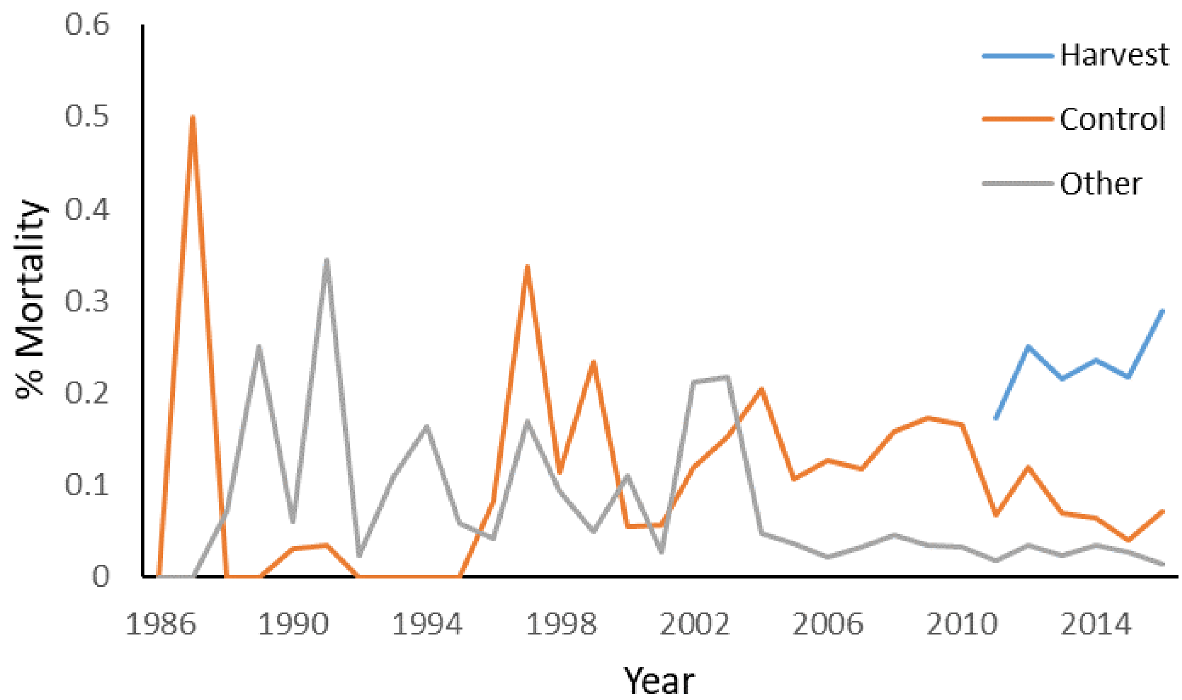


Figure 4: % of wolf population that died from harvest, control removals, and other human-caused mortality in Montana from 1986 to 2016.

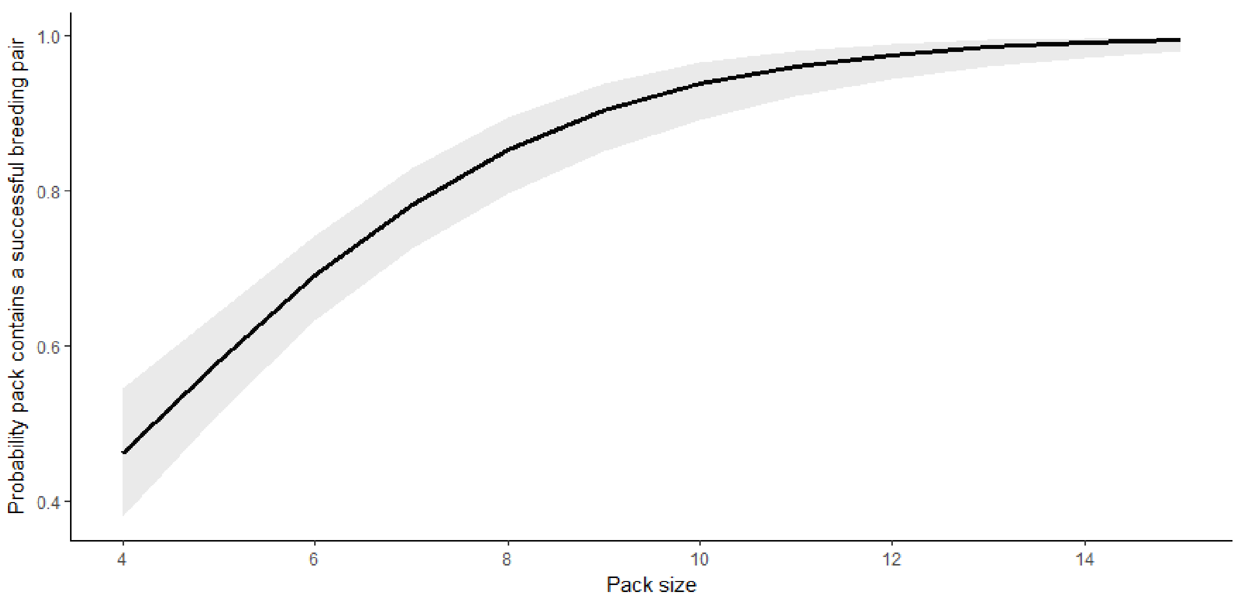


Figure 5: Probability a pack contains a successful breeding pair based on pack size in Montana with average population growth rate and % human-caused mortality at the population level from the delisted period (2009, 2011-2016).

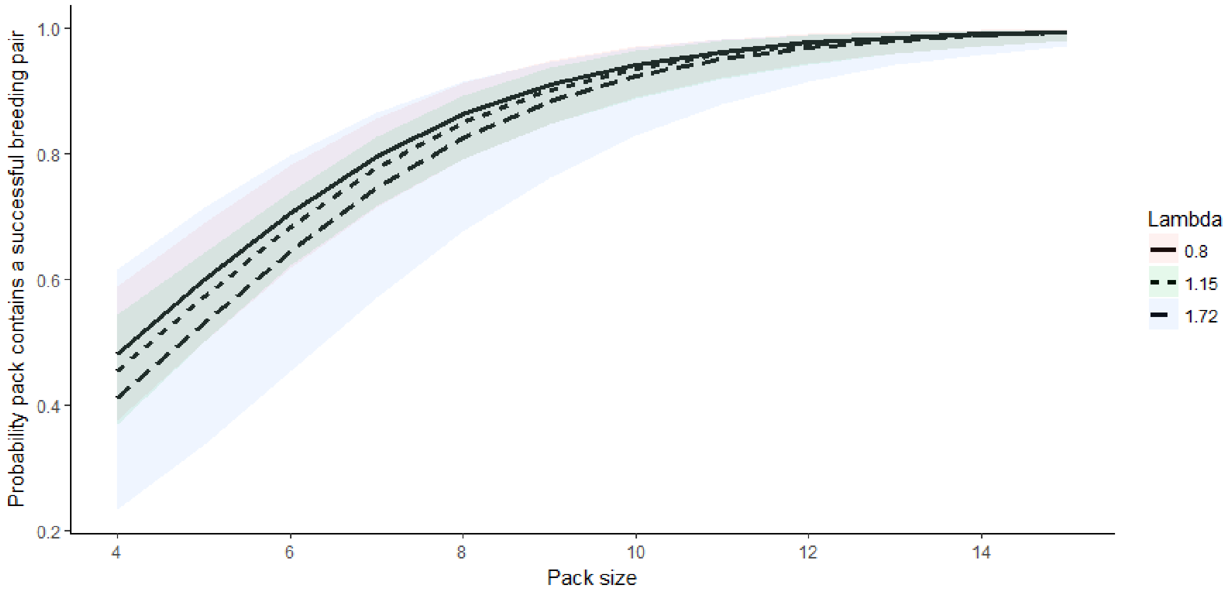


Figure 6: Probability a pack contains a successful breeding pair against pack size with the minimum, mean, and maximum population growth rate and the average % human-caused mortality at the population level for wolves in Montana during the delisted period (2009, 2011-2016).

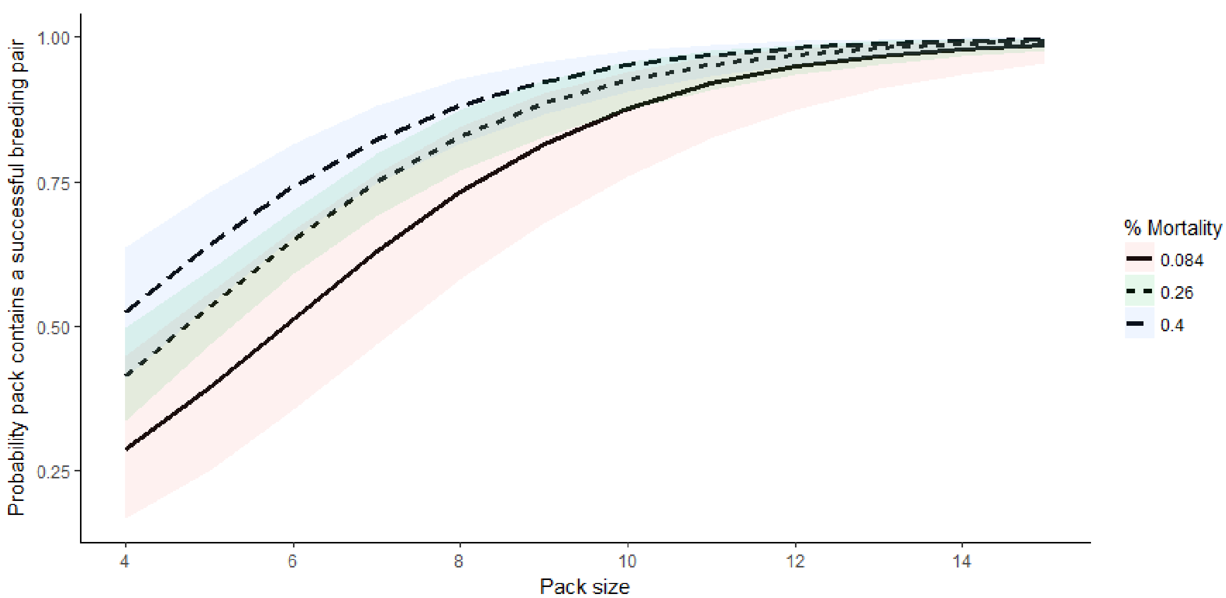


Figure 7: Probability a pack contains a successful breeding pair against pack size with the minimum, mean, and maximum % human-caused mortality at the population level and the average population growth rate for wolves in Montana during the delisted period (2009, 2011-2016).

5. ATTITUDES, PERCEPTIONS, AND VALUES OF RESIDENT MONTANANS RELATED TO WOLF HARVEST MANAGEMENT IN MONTANA

Investigators: Alex & Libby Metcalf (University of Montana); Mike Lewis, Quentin Kujala, Bob Inman & Justin Gude (Montana Fish, Wildlife and Parks)

Status: Final report completed

Following the 2016-17 wolf hunting/trapping seasons, Montana Fish, Wildlife & Parks (FWP) conducted four separate surveys of resident Montanans to better understand their views regarding wolves and wolf management in Montana. This research builds upon previous work of the agency to survey state residents in 2012. Survey finding revealed that tolerance for wolves on the Montana landscape remains relatively low. However, comparing the 2017 survey data to identical data collected in 2012 shows a slight shift in the direction of more tolerance for wolves over time, particularly among Montana households. Results also showed continued tolerance for wolf hunting in Montana across all four survey groups. In contrast, tolerance of wolf trapping varied substantially. While hunters and landowners were very tolerant of wolf trapping, nearly half of the respondents to the Montana household survey were not tolerant of wolf trapping in the state. Lastly, for each of the four survey groups there was little agreement among respondents regarding whether the regulations for the Montana wolf hunting and trapping seasons were satisfactory or not. These survey results speak to the contentious nature of wolf management in Montana, and the importance of continue efforts on the part of FWP to involve the public in wolf-related outreach and education, wolf management decisions, and season setting processes.

6. MINIMIZING AND MITIGATING WOLF/ LIVESTOCK CONFLICTS IN WASHINGTON

Investigators: Zoe Hanley and Robert Wielgus, Washington State University

Status: PhD dissertation completed

Preventing wolf-livestock conflicts requires identifying conditions placing livestock at risk and focusing outreach and adaptive management at a local scale. Risk mapping has become a popular tool to predict and display livestock depredation risk by carnivores worldwide. To date no maps predicting livestock depredation risk exist for the Northern Rocky Mountain gray wolf (*Canis lupus*) population. Historical (i.e., 1991 – 2008) data from Idaho and Montana were used to predict cattle depredation risk by gray wolves recolonizing Washington. Risk models were developed at two spatial scales, (1) wolf pack territory (n = 137) and (2) cattle grazing allotment (n = 69) to test hypotheses that cattle depredations by wolves were associated with wolf demographics, cattle and wild prey abundance, allotment characteristics, and land cover types. Within wolf pack territories, cattle depredation risk increased as cattle abundance and adult wolf removal increased and if the pack depredated the previous year. Adult wolf removal and pack size showed weaker evidence in their relationship with cattle depredation probability and the predicted number of cattle depredated. Similarly, cattle depredation risk increased for larger grazing allotments with more cattle, wolves, and grassland cover and decreased with pack reproduction and a later cattle turnout date. Wolf pack reproduction, cattle turnout date, and percent grassland cover indicated high variability in the direction of their relationship with cattle depredation probability and the predicted number of cattle depredated. Forecast maps for Washington identified hotspots of high (81 – 90%) depredation risk in Yakima, Kittitas, and Columbia counties. Cattle grazing allotments only occur east of the Cascade Mountains, and hotspots in Okanogan, Ferry, and Yakima counties were recognized as intermediate (61 – 80%) depredation risk. These risk models and maps provide locations to focus depredation prevention measures and a template for future analyses as wolves continue to recolonize Washington.

7. EVALUATING THE EFFECTIVENESS OF LIVESTOCK GUARDIAN DOGS: LOSS-PREVENTION, BEHAVIOR, SPACE-USE, AND HUMAN DIMENSIONS

Investigators: Graduate Student, Daniel Kinka, Utah State University, Principal Investigator, Julie Young, Ph.D., USDA APHIS/ Utah State University; Collaborators, Nathan Lance and Mike Ross, Montana Fish, Wildlife & Parks

Status: In Progress

Livestock guardian dogs (LGDs; Canis familiaris) have been widely adopted by domestic sheep (Ovis aries) producers and reduce the need for lethal management of livestock predators. LGDs were originally used in the United States to reduce coyote (Canis latrans) depredations, but their efficacy against larger carnivores is unclear. It is critical to identify which behavioral characteristics and LGD breeds are most effective at deterring different carnivores in order to maximize the utility of LGDs. Further, little attention has been given to how carnivores respond to sheep grazed with LGDs on open range, and whether successfully using LGDs to reduce livestock depredations can increase tolerance for predators. Our study investigated the effectiveness of multiple LGD breeds in the Western U.S. to determine best management practices for LGDs. Assuming a broad definition of LGD effectiveness, we investigated (1) predator-specific loss prevention, (2) breed-specific behavioral characteristics, (3) impact on the space use of endemic carnivore species, and (4) a potential mediating effect on tolerance for livestock predators. LGD breeds common in the U.S. were compared with three imported breeds currently underutilized in the U.S – Turkish kangals, Bulgarian karakachans, and Portuguese cão de gado transmontanos (henceforth "transmontanos"). To address these topics, from 2013 – 2016 we collected data on cause-specific sheep mortality, LGD behavior, occupancy of carnivores near grazing sheep bands, and pastoralists' attitudes towards LGDs and large carnivores throughout Idaho, Montana, Oregon, Washington, and Wyoming.

Results indicate that two of the novel breeds of LGD, kangals and karakachans, offer greater protection from certain predators than mixed-breed LGDs commonly used in the U.S. Turkish kangals were associated with a significant reduction in cougar (Puma concolor), black bear (Ursus americanus), and coyote depredations. Similarly, Bulgarian karakachans were associated with a significant reduction in coyote depredation. Kangals were also shown to be less effective at reducing wolf (Canis lupus) depredations than whitedogs, but this may have been due to an outlier in the data. Unfortunately, a small sample size of transmontanos coupled with an inability to get reliable sheep counts from certain collaborating ranchers, meant that transmontanos had to be dropped from this analysis.

Although LGDs of all breeds were behaviorally similar, some breed-specific differences in LGD behavior were also identified, via decoy tests and behavioral observations, that may help ranchers and wildlife managers make tailored decisions about how best to select LGD breeds. Kangals tended to be more investigative when engaging a decoy, karakachans more vigilant, and transmontanos more able to decipher a threatening from unthreatening stimuli. Transmontanos also spent less time scanning than whitedogs and there was a marginally significant effect of karakachans moving more than whitedogs. Perhaps the most interesting finding was the difference between kangals and karakachans; kangals preferring to investigate and karakachans preferring to keep their distance from a decoy. Ranchers and LGD breeders will occasionally mention the observation that some LGDs tend to stay close to sheep at all times while others are more likely to patrol. We are currently using GPS data collected from LGDs to parse whether these patterns of space use are breed-specific. Nevertheless, the difference we observed between kangals and karakachans in terms of willingness to engage may confirm that kangals are more of a "patrol dog" and karakachans more of a "sheep-tending dog." Although both techniques appeared effective, it is worth mentioning that karakachans were unpopular with our collaborators throughout the study. Even the most practiced and tenacious sheep producers often had difficulty getting sheep to bond to their karakachans, and thus have their karakachans successfully integrate with the flock. This may have been a result of karakachans' generally darker coat and squatter build – unfamiliar to most U.S. sheep – but the supposition was not tested. Despite their being unpopular amongst our collaborators, karakachans were found to be better than whitedogs at defending against coyote depredation. All of which suggests that perceptions about LGD effectiveness may not always mirror reality, and that the success of any new breed of LGD will hinge on more than its guarding abilities alone.

Results of our study also show that sheep grazing with LGDs tends to displace wolves and attract many smaller carnivore species. We detected that sheep grazed with LGDs act as a mild deterrent to wolves, decreasing the likelihood that they will be detected near a sheep band by about 75%. No effect of sheep and LGD presence was found for grizzly bears (Ursus arctos), black bears, or cougars. We also detected an increase in detection of smaller carnivores when a sheep band was present, including coyotes, red foxes (Vulpes vulpes), and bobcats (Lynx rufus). The increase in mesopredator detections may suggests a short-term mesopredator release accompanying the decrease in wolf detectability when sheep were present. However, our results may also have been an effect of scale. For wolves, it is possible to simply move to another part of their home range when sheep and LGDs are present. Smaller carnivores with smaller home ranges may have been more inclined to try and take advantage of an abundant food source that appeared within their home range. These results are unique in that they attempt to discuss LGDs and livestock grazed on open range in the context of ecological theory. In terms of loss-prevention, how spatial interactions influence LGD effectiveness against grizzly bears, black bears, cougars, and coyotes will require further study, but effectiveness does not seem to be mediated by intraguild space-use interactions. With wolves however, LGDs seem to be effective deterrents.

Our survey of pastoralists revealed that, although attitudes about LGDs are generally very positive, they do not temper attitudes towards wolves and grizzly bears. Believing that LGDs reduce pastoralists' reliance on government assistance and lethal removal of predators was associated with higher opinions of both wolves and grizzly bears, but these opinions were inversely related to length of time using LGDs, and not modified by beliefs about LGDs' usefulness as a tool for managing large carnivores. This suggests that pastoralists' attitudes about large carnivores are dictated by more than just the practical and economic threats they pose to the ranching industry. These results discuss LGDs and non-lethal management tools in the context of psychosocial theories of tolerance, acceptance, and decision making. While a small sample size prohibited a more nuanced look at the data, and limited its potential inference, it is still the largest study of LGDs' effect on attitudes towards large carnivores to date. With a larger sample size, structural equation modeling could have been used to investigate the Hazard-Acceptance model of wildlife tolerance, and it is still a potential avenue for further investigations.

This study advances the scientific understanding of LGDs, how they work, when they work, and what are there ecological impacts. It provides useful insight to ranchers and wildlife managers on the strengths and weakness of different breeds of LGDs and facilitates more informed use of LGDs to reduce livestock depredations. It also provides ranchers and wildlife managers an initial investigation of carnivore responses to sheep bands grazing on open range. For conservationists, especially any concerned about facilitating recovery of large carnivore populations by increasing tolerance, it suggests that LGDs are not a panacea. Finally, the study draws attention to future research opportunities concerning LGDs that go beyond loss-prevention.

Products of this study include two peer-reviewed scientific publications, listed below. We expect to produce 2-3 more publications and a dissertation within the next year. Study products to date:

Kinka, D., Young, J.K. in press. A livestock guardian dog by any other name: similar response to wolves across livestock guardian dog breeds. Rangeland Ecology and Management https://doi.org/10.1016/j.rama.2018.03.004.

Ribeiro, S., J. Dornig, A. Guerra, J. Jeremic, J. Landry, D. Mettler, V. Palacios, U. Pfister, S. Ricci, R. Rigg, V. Salvatori, S. Sedefchev, E. Tsingarska, L. van Bommel, L. Vielmi, J. Young, and M. Zingaro. 2017. Livestock guarding dogs today: Possible solutions to perceived limitations. Carnivore Damage Prevention News, Summer (15)36-53.

APPENDIX 3.

MONTANA WOLF PACK TABLE

Key to Notation in Pack Table:

1 Underlined packs are counted as breeding pairs tow ard Montana state plan goals. CSKT = Flathead Indian Reservation; BFN = Blackfeet Indian Reservation.
2 Excludes w olves killed in control actions to address livestock depredation and law ful public harvest.
3 Does not include pups that disappeared before w inter.
4 Number legally harvested by humans in caledar year 2017.
5 Agency lethal control. Includes w olves killed by private citizens to defend livestock or under terms of a kill permit.
6 Collared w olves that became missing in 2016.
7 Includes only domestic animals confirmed killed by w olves.
Border pack shared w ith the State of Idaho; dens in Montana.
* Border pack shared w ith Yellow stone National Park; more time in Montana

Table A4. Montana Wolf Packs and Population Data, 2017.

REF		FWP	MIN. ESTIMATED			DOCUMENTED MORTALITIES					KNOWN		CONFIRMED LOSSES[7]			
#	WOLF PACK[1]	Region	PACK SIZE DEC 2017	Breeding Pair	Count Quality	NATURAL	HUMAN[2]	UNKN[3]	HARVEST[4]	CONTROL[5]	DISPERSED	MISSING[6]	CATTLE	SHEEP	DOGS	OTHER
1	Akokala	R1	4	Y	G				1							
	Ashley	R1	?	?	P				1							
	~~Baptiste~~	R1	.	.	.											
2	Bearfite	R1	3	N	M											
	~~Bisson (CKST)~~	R1	.	.	.											
3	Bull River	R1	5	Y	G											
4	Cabinet	R1	12	Y	G				2							
5	Candy Mountain	R1	4	N	G				1							
6	Cilly	R1	10	Y	G		1									
7	Condon	R1	9	Y	G											
	Corona	R1	?	?	P				3							
8	Cow ell	R1	3	Y	G											
9	Crane Mtn	R1	5	Y	G											
10	Dutch	R1	7	Y	G											
	Echo	R1	?	?	P				1							
11	Firefighter	R1	5	Y	G											
12	Fisher Mountain	R1	3	?	M				1							
13	Fishtrap	R1	2	N	M				5							
14	Flathead Alps	R1	2	N	P											
15	Garden (CSKT)	R1	2	N	P											
16	Good Creek	R1	10	Y	G				1							
	Grave Creek	R1	?	?	P				2							
	~~Great Bear~~	R1	.	.	.											
	Great Northern	R1	?	?	P				1							
17	Half Moon	R1	2	N	M				2							
18	Hog Heaven	R1	5	N	G				5							
19	Irvine	R1	8	Y	G											
20	Kerr	R1	5	N	G								1			
21	Kintla	R1	10	Y	G											
	Kootenai	R1	?	?	P				1							
22	Ksanka	R1	4	Y	G				3							
23	Lazy Crk	R1	8	Y	G				1							
	~~Lonepine~~	R1	.	.	.											
	Lamoose	R1	?	?	P				2							
24	Lost #	R1	3	?	M											
	Lost Dog	R1	?	?	P				1							
	~~Lost Girl~~	R1	.	.	.											
	~~Lost Soul~~	R1	.	.	.											
25	Lydia	R1	7	Y	G				1							

…Continued… Table A4. Montana Wolf Packs and Population Data, 2017.

REF #	WOLF PACK[1]	FWP Region	MIN. ESTIMATED PACK SIZE DEC 2017	Breeding Pair	Count Quality	DOCUMENTED MORTALITIES NATURAL	HUMAN[2]	UNKN[3]	HARVEST[4]	CONTROL[5]	KNOWN DISPERSED	MISSING[6]	CONFIRMED LOSSES[7] CATTLE	SHEEP	DOGS	OTHER
	~~McDonald~~	R1	.	.	.											
	~~McKay~~	R1	.	.	.											
	Moore	R1	?	?	M				2							
	Mullan	R1	?	?	P											
26	Murphy Lake	R1	9	Y	G				2							
	~~No~~	R1	.		.											
27	Noisy	R1	3	N	M				4							
	~~Nyack~~	R1	.	.	.											
	~~O'Brien~~	R1	.	.	.											
28	Pierce	R1	3	N	G											
29	Pistol Creek (CSKT)	R1	6	Y	G											
30	Pleasant Valley	R1	6	Y	G				3				3			
31	Preacher #	R1	3	N	G											
32	Quintonkon	R1	4	Y	G											
33	Satire	R1	5	N	G											
34	Schafer	R1	4	N	G											
	~~Silcox~~	R1	.	.	.											
35	Sleeping Woman (CSKT)	R1	12	Y	G											
	~~Smoky~~	R1	.	.	.											
36	Solomon Mountain #	R1	7	Y	G											
37	Spotted Bear	R1	5	N	M				1							
38	Summit Creek	R1	4	N	M				1							
	~~Sundance~~	R1	.	.	.											
	~~Tallulah~~	R1	.	.	.											
	~~Thompson Peak~~	R1	.	.	.											
	~~Tom Meir~~	R1	.	.	.											
39	Twilight #	R1	2	N	M											
40	Valley Creek (CSKT)	R1	4	N	G									6		
	~~Vermillion~~	R1	.	.	.											
41	Weigel	R1	5	Y	G				2							
42	Whale Creek	R1	5	Y	G				1							
	Whitefish	R1	?	N	P				2							
	~~Wiggletail #~~	R1	.	.	.											
	Wolf Prairie	R1	?	?	P				1							
43	Yaak	R1	12	Y	G				2							
44	Alta #	R2	3	N	G				2							
45	Ambrose	R2	7	Y	G				2							
46	Arrastra Creek	R2	8	Y	M				1							
47	Avon	R2	4	N	M				3	1			1			
48	Belmont	R2	5	?	M				2							
49	Black Pine	R2	2	N	P											
50	Bugle Mountain	R2	2	?	P											

…Continued… Table A4. Montana Wolf Packs and Population Data, 2017.																
REF #	WOLF PACK[1]	FWP Region	MIN. ESTIMATED PACK SIZE DEC 2017	Breeding Pair	Count Quality	DOCUMENTED MORTALITIES NATURAL	HUMAN[2]	UNKN[3]	HARVEST[4]	CONTROL[5]	KNOWN DISPERSED	MISSING[6]	CONFIRMED LOSSES[7] CATTLE	SHEEP	DOGS	OTHER
51	Cache Creek #	R2	5	Y	G				3							
52	Chamberlain	R2	3	N	M				1	5			8			
53	Conger Point	R2	2	N	P											
54	DeBorgia #	R2	6	Y	G				3							
55	Divide Creek	R2	9	Y	G				3	1			1			
56	East Fork Rock Creek	R2	4	Y	M											
	El Capitan	R2	?	?	P											
57	Evaro	R2	2	N	G											
58	Flint	R2	4	?	M				1							
59	Gash Creek #	R2	4	?	M											
60	Gird Point	R2	2	?	P				1							
61	Humbug	R2	2	?	M				2							
62	Inez	R2	9	Y	G				3							
63	Landers Fork	R2	4	?	P				1							
64	Miller Peak	R2	2	N	M											
65	Mineral Mountain	R2	8	Y	M				3							
66	Morrell Mountain	R2	4	Y	G				4							
67	Ninemile	R2	4	?	M				1							
68	Olson Peak	R2	3	?	M				3							
69	One Horse	R2	5	Y	G		1		1	3			1			
70	Overwhich #	R2	4	?	M			1								
71	Petty Creek	R2	4	Y	G				2							
72	Quartz Creek	R2	5	?	P				2							
73	Ross' Fork	R2	5	Y	G				3							
74	Savenac	R2	5	?	M				3							
75	Seeley Lake	R2	7	Y	G				1							

...Continued... Table A4. Montana Wolf Packs and Population Data, 2017.

REF #	WOLF PACK[1]	FWP Region	MIN. ESTIMATED PACK SIZE DEC 2017	Breeding Pair	Count Quality	DOCUMENTED MORTALITIES NATURAL	HUMAN[2]	UNKN[3]	HARVEST[4]	CONTROL[5]	KNOWN DISPERSED	MISSING[6]	CONFIRMED LOSSES[7] CATTLE	SHEEP	DOGS	OTHER
76	Siegel Mountain	R2	5	Y	G		2									
77	Silver Lake #	R2	6	Y	M											
78	Sliderock Mtn	R2	3	N	M				1							
79	Stonewall Mountain	R2	4	N	M				2	3				3		
80	Sula	R2	5	Y	G											
81	Sunflower Mountain	R2	9	Y	G				1							
82	Sunrise Mountain	R2	3	N	G											
83	Taft	R2	2	?	M											
84	Telephone Butte	R2	6	Y	M				3							
85	Tepee Point	R2	5	Y	M	1			1							
86	Trapper Peak	R2	4	N	M				1							
87	Union Peak	R2	4	?	P				1							
88	Watchtower #	R2	2	N	G											
	~~Highlands~~	R3	.	.	.					2						
89	Thunderbolt	R3	4	N	G				2							
90	Anaconda	R3	4	Y	G				1	1			1			
	~~Bloody Dick #~~	R3	.	.	.				3	10			3			
91	Dyce	R3	6	Y	G				1				1			
92	Four Eyes #	R3	4	N	G				1							
93	Fox Creek	R3	6	Y	G				3	1						
94	Pyramid #	R3	3	N	G				2							
	~~Vipond~~	R3	.	.	.		1									
95	Warmsprings	R3	12	Y	G					7			7			
	Anteolpe Basin	R3	?	?	P											
96	Beartrap	R3	11	Y	G	1			2							
97	Cedar Creek	R3	2	Y	G				4							
98	Centennial	R3	2	Y	M				4	5			3	2		
	Cougar 2	R3	?	?	P											
99	Hayden*	R3	6	Y	M				5							
100	Meadow Creek	R3	5	N	G	1			2							

...Continued... Table A4. Montana Wolf Packs and Population Data, 2017.

REF #	WOLF PACK[1]	FWP Region	MIN. ESTIMATED PACK SIZE DEC 2017	Breeding Pair	Count Quality	DOCUMENTED MORTALITIES NATURAL	HUMAN[2]	UNKN[3]	HARVEST[4]	CONTROL[5]	KNOWN DISPERSED	MISSING[6]	CONFIRMED LOSSES[7] CATTLE	SHEEP	DOGS	OTHER
101	Price Creek	R3	3	?	P											
102	Sweetwater	R3	3	?	P											
	Toadflax	R3	?	?	P				1							
103	Battle Ridge	R3	6	Y	M				3	4	1		2			
104	Cinnabar*	R3	7	Y	G				2						1	
105	Hogback	R3	9	Y	M				4							
	Porcupine Creek	R3	?	?	.											
106	Shinglemill	R3	5	Y	M				3							
107	Slip n' Slide	R3	2	N	G				6		1	1				
108	Steamboat Peak	R3	8	Y	G				5							19
109	Bennie (BFN)	R4	6	Y	G				4	1			6			
110	Blowout Mountain	R4	7	Y	G				7	2						
111	Chief Mtn (BFN)	R4	10	?	M											
112	Crown Mtn	R4	10	Y	G				6							
113	Deep Creek	R4	2	N	G				2	3			2			
114	Dog Gun (BFN)	R4	4	?	P				1							
115	Flesher Pass	R4	3	?	M					3			1	1		
116	Livermore (BFN)	R4	6	?	P											
117	Looking Glass (BFN)	R4	2	?	P											
118	Marias	R4	4	?	P											
119	Pretty Prairie	R4	8	Y	M											
120	Red Shale	R4	8	Y	G											
121	Teton	R4	6	Y	G				1							
122	Avalanche	R4	4	?	M				1							
123	Baker Mountain	R5	5	Y	M				1				1			
	Cayuse Hills	R5	?	?	.											
124	Rosebud	R5	2	N	G				2				1			
	R1 Misc/Lone	R1							11	1						
	R2 Misc/Lone	R2					2		13							
	R3 Misc/Lone	R3					4		13	4			6			
	R4 Misc/Lone	R4		.	.											
	R5 Misc/Lone	R5														
Montana Totals			633	63		3	11	1	233	57	2	1	49	12	1	19