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Evaluating carnivore harvest as a tool for increasing elk calf survival and recruitment

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Project Background

Since the early 1940s, the estimated statewide elk population in Montana has increased eight-fold, partially because of management efforts conducted in response to public demand for increased recreational opportunities (Montana Fish, Wildlife and Parks 2004). Elk are an iconic species throughout the western United States and play a large role across ecological (Kauffman et al. 2010), social (Haggerty and Travis 2006) and economic (U. S. Department of the Interior 2011) landscapes. However, since the early 2000's, declines in elk numbers and recruitment in some parts of the western United States resulted in concerns that the recovery of large carnivores such as wolves (*Canis lupus*), mountain lions (*Puma concolor*) and grizzly bears (*Ursus arctos*) has affected elk populations (Bunnell et al. 2002, Cook et al. 2013). Thus, wildlife managers are increasingly focused on understanding and managing the effects of predation on elk populations. Carnivore recovery is important to elk populations because predation may be a proximate limiting and regulating factor for many elk populations (Messier 1994, Hebblewhite et al. 2002. Garrott et al. 2008, Andren and Liberg 2015). In addition to carnivore recovery, changing elk harvest management prescriptions, shifts in land use, and changing habitat and climatic conditions all contribute to a complex suite of variables with the potential to affect elk population dynamics. Because of this complexity, understanding the effects of predation on elk population dynamics is difficult and determining appropriate management actions is challenging.

To detect and respond to fluctuations in wildlife populations, managers require information on the factors that influence population dynamics. Survival of prime-aged females and recruitment can both have strong impacts on a population's trajectory (Gaillard et al. 1998, 2000; Eacker et al. 2016). However, while adult female survival is often high and relatively stable (Nelson and Peek 1982, Garrott et al. 2003), juvenile survival tends to be highly variable and consequently, may be a more common driver of ungulate population dynamics (Raithel 2007, Harris et al. 2008). Recruitment, which incorporates fecundity and juvenile survival to age l, represents an important demographic parameter that wildlife managers often use to track trends in population growth rates (DeCesare et al. 2012). Although direct assessments of juvenile survival using marked animals offers the most accurate and informative measure of recruitment, such data are difficult and expensive to collect and may not be a feasible option. As a less expensive and less time intensive alternative, age ratios (i.e., number of juveniles per 100 adult females) offer an index of recruitment often used by managers to monitor populations (Harris et al. 2008). Such extensive spatio-temporal data sets offer the potential for monitoring changes in recruitment and assessing long-term trends in populations (Harris et al. 2008, DeCesare et al. 2012).

In west-central Montana, MFWP administrative Region 2 supports a healthy black bear population, and the numbers and geographic ranges of wolves, mountain lions, and grizzly bears have expanded during the past 10 years. Hunting districts in three watersheds with high carnivore densities have experienced declining trends in elk numbers and recruitment and are currently below elk population objectives. Mountain lion predation and, to a lesser degree, wolf predation, have been documented as important sources of elk calf mortality in this region (Eacker et al. 2016). In an effort to reduce predation on elk in areas with high carnivore densities and declining elk numbers, wildlife managers have applied integrated carnivore-ungulate management strategies over the past 5 years. In conjunction with reduced or eliminated antlerless elk harvest throughout most of the region, carnivore harvest quotas have been increased in an attempt to reduce wolf and mountain lion populations.

When wolf management returned to the State of Montana and hunting resumed in 2011, MFWP liberalized wolf hunting regulations for each of the following 3 years. These changes included adding a trapping season, removing the state-wide quota, extending the season, and increasing bag limits for individual hunters. Additionally, in February 2012 a mountain lion harvest management prescription that increased harvest levels, particularly of female mountain lions, was applied in efforts to reduce predation effects on elk in the western portion of MFWP Region 2, while still conserving mountain lion populations and providing the desired mountain lion hunting opportunity. The prescribed mountain lion harvest management regulations were designed to reduce mountain lion density by 30% over a period of 3 years across approximately 60% of the region, and manage mountain lions for stability, generally at current levels, across the remaining 40% of the region.

Although these steps were implemented to reduce predation on ungulate prey species, there is uncertainty over the ability of liberalized carnivore harvest management prescriptions to achieve harvest levels that will affect carnivore densities at the landscape level. Furthermore, reducing carnivore densities may or may not result in increasing elk calf survival and recruitment because the degree to which predation by each carnivore species is compensatory with other biotic and abiotic mortality factors is unknown. As a result, the effectiveness of carnivore harvest as a tool for increasing elk recruitment and population size is unknown and has not been evaluated.

These recent changes in wolf and mountain lion management in west-central Montana provide a unique opportunity to build on a recently completed project and conduct a robust, multi-scale Before-After-Control-Impact evaluation of the effects of carnivore management on carnivore population density and elk calf survival and recruitment. During 2012 and 2103, we estimated pre-treatment mountain lion density in an area managed for mountain lion reduction (south Bitterroot area) and an area managed for stability (upper Clark Fork area). To assess the effects of mountain lion harvest management on mountain lion population density, we will compare mountain lion densities in these treatment and control areas before and after 4-years of increasing mountain lion harvest quotas in the south Bitterroot area.

To evaluate the effects of carnivore management on elk calf survival and recruitment more broadly, we will conduct a regional evaluation of elk recruitment ratios and a focused evaluation of elk calf survival in the south Bitterroot study area to detect changes in the rate of wolf and mountain lion caused calf mortality. At the regional scale, we will use age-ratio data collected during annual spring surveys to evaluate changes in elk recruitment during different carnivore population and management regimes. This will allow us to broadly evaluate factors affecting recruitment over an extended period of time. On a finer scale, we will compare baseline data on elk calf survival and cause-specific mortality collected before and after 4 years of adapted carnivore management to determine if mountain lion predation and wolf predation rates decreased, and if calf survival and recruitment increased. The baseline elk calf survival and cause-specific mortality rate data were collected as part of a project conducted in the south Bitterroot area during 2011-2013. Building from these efforts, the purpose of this project is to evaluate elk calf survival and cause-specific mortality, as well as carnivore densities, to assess the effect of carnivore harvest management prescriptions on carnivore densities and elk calf survival.

Location

Elk calf survival and mountain lion population estimation is focused primarily within Ravalli County, Montana. Portions of this project also occur in Mineral, Missoula, Granite, Deer Lodge, and Powell Counties.

Study Objectives (2017-2018)

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.

Objective #1: Elk calf survival monitoring

To evaluate the effects of carnivore management on elk calf recruitment we are estimating survival and cause-specific mortality of elk calves in the south Bitterroot area. The 3,350 km^2 (Proffitt et al. 2015*a*) southern Bitterroot valley study area, located in west-central Montana, includes the drainages of the East Fork and the West Fork of the Bitterroot watershed. The East Fork and the West Fork, hunting districts HD 270 and HD 250 respectively, are home to the two elk populations that are the focus of this study. Additionally, the East Fork population has a migratory segment with a summer range in the Big Hole Valley (HD 334, Proffitt et al. 2015*a*).

The East Fork study area encompasses 1,719 km^2 and has an elevational range of 1,100-2,800 m. Portions of the East Fork are heavily roaded, and the area is 18% private land. In comparison to the West Fork, the East Fork consists of more modest terrain, and is characterized by heavy agricultural use and open grasslands which give way to timbered slopes, sub-alpine, and alpine terrain (Proffitt et al. 2015*a*).

The West Fork study area encompasses 1,437 km^2 and has an elevational range of 1,200-3000 m. The West Fork is comprised mostly of public land (95%), with high road accessibility at lower elevations and fewer roads at higher elevations (Proffitt et al. 2015*a*). The West Fork is characterized by heavily forested areas and lower riparian grasslands, and alpine terrain at higher elevations.

We will estimate calf survival in the southern Bitterroot and compare it to the baseline data collected in the same area prior to changes in carnivore harvest regulations. By comparing mountain lion and wolf predation rates before and after liberalized carnivore harvest regulations, we will evaluate the effect of carnivore harvest management on predation of elk calves.

1.1 Elk calf survival June 1, 2016 – May 31, 2017

Overview

In 2016 we instrumented 121 elk calves with ear-tag radio transmitters designed to emit a mortality signal if no movement was detected within four hours. Eighty-one of these calves were tagged as neonates during spring capture efforts in May and June 2016, and 40 were tagged at about 6-months of age during December 2016 and January 2017.

Table 1.1 *Number of calves sampled in cohort number one between the East Fork and West Fork study areas during neonate (spring) and 6 month (winter) captures.*

	East Fork	West Fork
May-June 2016	56	20
Dec. 2016-Jan. 2017	25	20

We monitored all tagged calves tagged as neonates for one year and calves tagged in early winter at approximately 6 months of age for 6 months until approximately one year of age. Monitoring of all instrumented calves started on the day following capture. From 27 May 2016 to 31 August 2016, we monitored all calves every day. From 31 August 2016 to 31 May 2017, we monitored calves 4-5 days a week.

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 (p5% CI = 0.40 – 0.66).

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 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 (Table 1.2).

Table 1.2 *Yearly survival rates of elk calves in the upper Bitterroot study area.*

Cohort	Survival Rate	95% CI
2011	0.32	0.20 – 0.44
2012	0.44	0.31 – 0.56
2013	0.51	0.38 – 0.62
2016	0.44	0.33 – 0.53

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; Table 1.3).

Table 1.3 *Cause-specific mortality counts and proportions of mortalities attributed to each cause for calves tagged and monitored in the first calf cohort. Table only includes counts of instances where calf fate was known to be dead. Several tags were found with no evidence linking them to an actual mortality. These instances were deemed "unknown fate", and results were not included in this table.*

	Count	Proportion
Bear Predation	4	0.078
Mountain Lion Predation	9	0.176
Wolf Predation	6	0.117
Non-predation	9	0.176
Unknown Cause	23	0.450

1.2 *Elk calf monitoring and survival, June 1, 2017 – May 31, 2018*

Elk calf capture and sampling, 2017 cohort

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 (Table 1.4).

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. We recorded the sex, weight (kg), and morphometric measurements to estimate calf age.

Figure 1.1 *Hobbled and blindfolded neonatal elk calf. Note ear-tag radio transmitter in right ear.*

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.

Table 1.4 *Number of calves East Fork and West Fork calves in the 2017 cohort ear-tagged during neonate (spring) and 6-month (winter) captures.*

	East Fork	West Fork
May-June 2017	65	37
Nov. 2017-Jan. 2017	8	17

Calf survival monitoring

Using a combination of ground and aerial telemetry, we monitored calf survival daily until 31 August 2017 due to high rates of neonate mortality reported in previous studies of elk calf survival (Barber-Meyer et al. 2008). After 31 August, we monitored calves 4-5 times per week and will continue with this schedule until 31 May 2018.

In addition to survival monitoring, we conducted aerial telemetry from fixed-wing aircraft to locate each calf 1-2 times per month from date of capture to 31 August 2017, and from 1 December to 31 May 2018. Due to hunting seasons in the area, we did not locate calves from 31 August – 27 November 2017. We will use calf locations to quantify the effects of spatially variable risk factors such as weather, forage, and carnivore distribution on individual calf predation risk.

Calf survival and cause-specific mortality

When a mortality event was detected, we promptly located the mortality site and performed a detailed necropsy to determine the cause of mortality. We categorized mortality sources as mountain lion predation, wolf predation, bear predation, coyote predation, unknown predation, unknown cause, unknown fate/tag loss or natural non-predation. We used characteristics such as consumption pattern, location and presence of claw marks, location and presence of subcutaneous hemorrhaging, width and presence of bite marks, and general features of the kill site to draw a conclusion about the cause of each mortality event (Figure 1.2). At each mortality site, we searched the area for signs of carnivores and submitted scat or hair for DNA analysis to definitively determine carnivore species. We skinned the carcass to look for possible hemorrhaging around bite and claw marks to differentiate predation from scavenging. We swabbed areas likely to contain carnivore saliva, such as hemorrhaged areas, ear tags with bite marks, and chewed bones, with Dacron swabs sterilized by 95% ethanol and submitted them for DNA analysis along with carnivore scat and hair.

Figure 1.2 *Cache pile consisting of grass and twigs covering an elk calf carcass.*

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” (Table 1.4). 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 (Table 1.5).

Table 1.4 *Fate of East Fork and West Fork calves in the 2017 cohort. The monitoring period will continue until May 31^{t}, 2018*

Calf Fate	East Fork	West Fork
Live	34	33
Dead	18	13
Unknown Fate	19	10
Total	**71**	**56**

Table 1.5 *Causes of East Fork and West Fork calf mortality in the 2017 cohort.*

Cause of Mortality	East Fork	West Fork	Total
Bear	0	0	0
Lion	7	3	10
Wolf	1	1	2
Natural Non-Predation	2	6	8
Unknown Predation	1	1	2
Unknown Cause	7	2	9
Unknown Fate	19	10	29

Objective #2: 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 2103, 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, Figure 2.1) in MFWP 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.

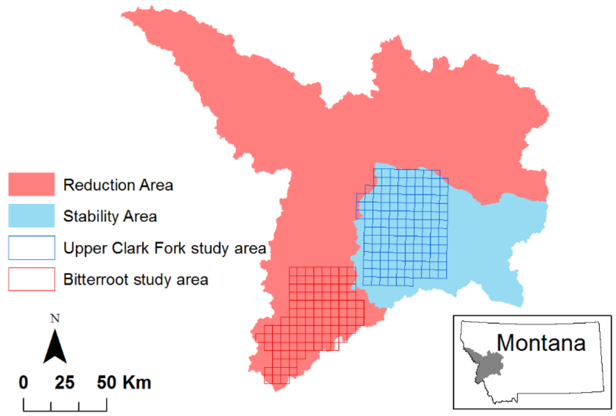

Figure 2.1 *Mountain lion harvest management goals in west-central Montana during 2012-2015 were to reduce mountain lion density by 30% across a portion of the region (shaded red) and maintain stable densities across a portion of the region (shaded blue). The south Bitterroot study area (red grid) was located in an area managed for a 30% reduction in mountain lion. density and the Upper Clark Fork study area (blue grid) was located in an area managed for maintaining stable mountain lion density.*

2.1 Mountain lion harvest regulations and harvest

The southern Bitterroot (Ravalli County) study area includes hunting districts (HD) 250 and 270 and is within the watershed being managed for population reduction. In December 2012, median mountain lion density was estimated at 4.5 (95% CI = 2.9, 7.7) and 5.2 (95% CI = 3.4, 9.1 mountain lions/100km^2 in HD250 and 270 respectively (Proffitt et al. 2015*a*). The 2011 regulations included a subquota of 3 females in both hunting district (HD) 250 and 270, equating to 1.8 female licenses per 1,000km^2 (Table 2.1). In 2012 and 2013 regulations included 14 special licenses with subquotas of 7 females in both HD 250 and 270, equating to 4.2 female licenses per 1,000km^2. After 2013, female harvest levels were reduced. In 2016, regulations included subquotas of 3 and 5 females in HD 250 and 270 respectively, equating to 2.4 female licenses per 1,000km^2.

The Upper Clark Fork (Granite County) study area includes portions of HDs 210, 211, 212, 213, 214, 2015, 2016, and 217 and is located within the watershed being managed for stability. In December 2013, median lion density was estimated at 1.6 mountain lions per 100 km^2 (MFWP, unpublished data). The 2010 and 2011 regulations for these areas included female subquotas equating to 1.2 female licenses per 1,000km^2 (Table 2.1). In 2012 and thereafter, regulations included female subquotas equating to 0.5-0.9 female licenses per 1,000km^2.

Table 2.1. *Mountain lion harvest quotas and harvest in the two hunting districts in the south Bitterroot study area. The south Bitterroot study area is located within a watershed managed for mountain lion population reduction and included portions of HD 250 and 270.*

[1] During 2009-2011, there was no male subquota, only a female subquota and total harvest quota.
[2] There was a boundary change that expanded HD 270 and reduced the size of HD 250.

Year	*HD 270 Harvest Quota*			*HD 270 Harvest*		*HD 250 Harvest Quota*			*HD 250 Harvest*		*Female licenses per 1000 km²*
	Female	Male	Total	Female	Male	Female	Male	Total	Female	Male	
2001	0	3		0	4	0	5		1	4	0.00
2002	0	3		0	3	0	5		0	5	0.00
2003	0	2		0	2	0	5		0	5	0.00
2004	0	1		0	1	0	2		0	3	0.00
2005	0	2		0	2	0	3		0	6	0.00
2006	0	3		0	4	0	4		0	3	0.00
2007	0	3		0	2	0	4		0	4	0.00
2008	0	3		0	1	0	4		0	1	0.00
2009	1	-	10[1]	1	4	1	-	10	1	3	0.60
2010	2	-	15	1	8	2	-	15	2	3	1.20
2011	3	-	20	3	6	3	-	20	3	4	1.80
2012	7	7		6	7	7	7		9	5	4.20
2013	6	4		7	4	6	4		4	6	3.60
2014[2]	4	5		5	5	3	5		1	3	2.10
2015	5	6		2	6	3	5		2	5	2.40
2016	5	6		6	5	3	5		2	2	2.40

Table 2.2. *Mountain lion harvest quotas and harvest in the Upper Clark Fork study area. The Upper Clark Fork study area is located within a watershed managed for maintaining stable mountain lion populations, and included portions of HD 210, 211/216, and 212/215/217.*

Year	*HD 210 Harvest Quota*			*HD 210 Harvest*		*HD 211/216 Harvest Quota*			*HD 211/216 Harvest*		*HD 212/215/217 Harvest Quota*			*HD 212/215/217 Harvest*	
	Female	Male	Total	Female	Male	Female	Male	Total	Female	Male	Female	Male	Total	Female	Male
2001				3	2	9	7		4	2	6	4		6	4
2002	1	4		1	1	2	4		2	1	6	4		6	4
2003	1	2		1	2	3	2		2	3	6	4		6	5
2004	1	5		1	2	3	2		3	2	6	4		1	3
2005	1	2		0	2	3	2		0	1	2	4		2	3
2006	0	2		0	2	0	2		0	0	0	4		0	3
2007	0	2		0	2	0	2		0	2	0	2		0	1
2008	0	2		0	1	0	2		0	2	0	2		0	0
2009	0	2		0	2	0	2		0	2	0	2		0	2
2010	2	-	4[1]	0	2	4	-	10	2	4	1	-	4	0	2
2011	2	-	4	2	2	4	-	10	1	4	1	-	4	0	3
2012	0	7		0	2	2	5		2	3	0	6		0	6
2013	0	3		0	5	3	5		2	2	0	6		0	7
2014	1	3		1	2	3	5		2	2	1	6		2	7
2015	1	3		1	3	3	5		1	4	1	6		1	6
2016	1	3		0	3	3	5		2	3	1	6		2	2

Table 2.2 continued

[3]During 2010-2011, there was no male subquota, only a female subquota and total harvest quota.

Year	*HD 213/214 Harvest Quota*			*HD 213/214 Harvest*		*Female licenses per 1000 km^2*
	Female	Male	Total	Female	Male	
2001	1	1		0	0	2.33
2002	1	1		0	1	1.45
2003	1	1		1	0	1.60
2004	1	1		0	0	1.60
2005	0	1		0	0	0.87
2006	0	1		0	0	0.00
2007	0	1		0	0	0.00
2008	0	1		1	0	0.00
2009	0	1		0	1	0.00
2010	1	-	2	2	1	1.16
2011	1	-	2	1	2	1.16
2012	1	2		1	2	0.44
2013	1	2		2	2	0.58
2014	1	2		1	2	0.87
2015	0	2		0	3	0.73
2016	0	2		0	2	0.73

2.2 Mountain lion population estimate in the south Bitterroot study area, 2016-2017

We used a DNA-based spatially explicit capture-recapture modeling approach to estimate the density of mountain lions in the study area. We overlaid a 5 km x 5 km grid across the study area and assigned each cell a grid identification number (Figure 2.2). We randomly generated a list of grid cells and started search effort each day in the randomly assigned grid cell. Mountain lion hair, scat, and muscle samples were collected by hound handlers and trackers for genetic analysis to identify individual mountain lions. When a fresh mountain lion track was located, the hound handler would release trained hounds to locate and tree the mountain lion. Tracks were backtracked and inspected to determine if the mountain lion was independent or associated with a family group, and group size was recorded. Muscle samples were collected from treed animals using biopsy darts fired from a CO_2-powered rifle (Palmer Cap-Chur 1200c). When older mountain lion tracks were located, a tracker or hound handler would backtrack the tracks and collect any hair or scat samples along the tracks. All field crews used a Global Positioning System unit to record the length (in km) and location of their search effort. In Montana, the hide and skull of all mountain lions harvested must be presented to MFWP. During the mandatory check, inspectors collected a muscle sample from each harvested animal within the study area. We also collected samples from harvested lions in all adjacent hunting districts to determine if animals marked within the study area might have moved out of the study area. We included these, along with DNA samples from any management removals or incidental mortalities that occurred within the study area during the sampling period as part of our analysis and population estimates.

We collected mountain lion tissue samples from December 3, 2016 – March 31, 2017. We genotyped tissue samples to identify individuals using 12 variable microsatellite loci (Biek et al. 2006). Sex was assigned by genetic analysis. Spatial information from the search effort and information on harvested individuals was divided into four sampling occasions: December, January, February, and March. Search effort was distributed across 83 of 105 grid cells in December (4,646 km of search effort), 72 in January (3,131 km), 78 in February (3,199 km) and 59 in March/April (3,377 km). A total of 74 independent samples were included in this analysis, with 54 unique individuals identified (33 females and 21 males). Fourteen individuals were captured 2-5 times during the sampling period (10 individuals captured twice, 3 captured three times, and 1 captured five times). Individual grid cells contained 0-5 samples (Figure 2.3). Eighteen individuals were harvested (9 females and 9 males), 14 of which were not detected by the search effort. Fourteen individuals (6 males and 8 females) were fitted with GPS collars programmed to collect 8 locations per day (Telonics model TGW-4477-4, Mesa, AZ).

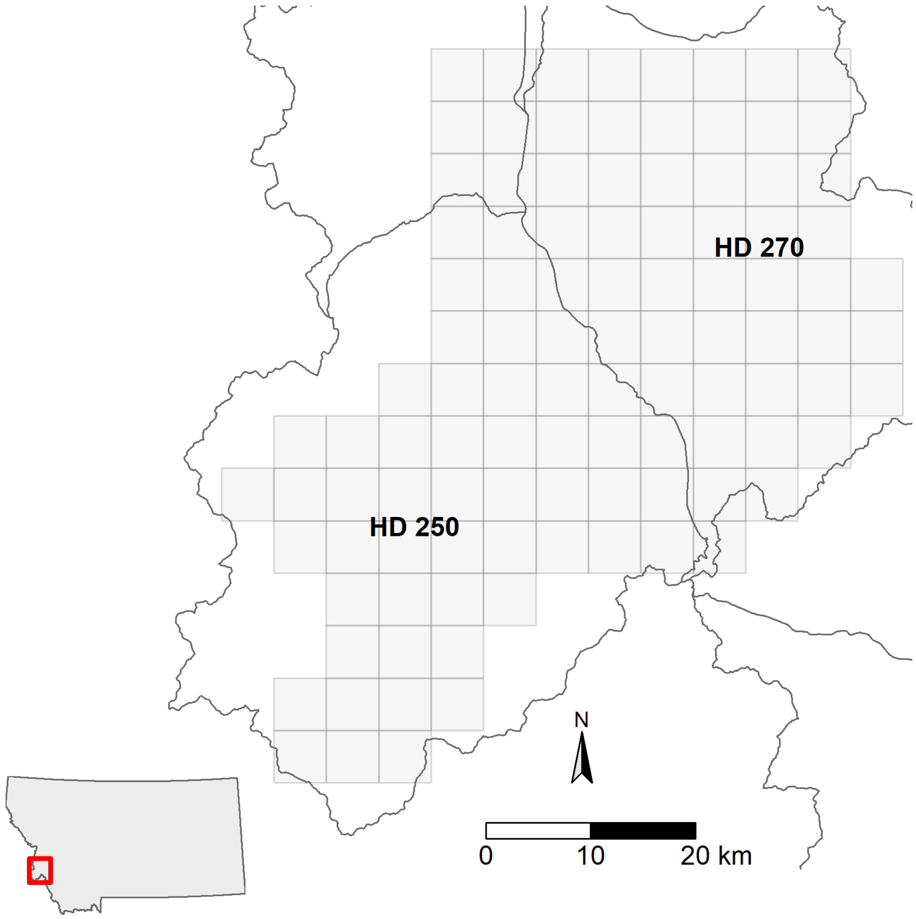

Figure 2.2. *Bitterroot study area, including the two management areas of interest: hunting districts 250 and 270. The study area was overlain by a trapping grid comprised of 5 km x 5 km grid cells (seen in gray, 105 total) for the spatially unstructured sampling design.*

We used a spatially explicit capture-recapture model derived from the hierarchical model formulation of a spatially unstructured capture-recapture model (Royle et al. 2009) to estimate population abundance and density. Fundamentally, modeling the probability of detection of mountain lions in each grid cell as a function of distance from mountain lion activity centers facilitates the estimation of density while overcoming limitations of traditional capture-recapture approaches. Mountain lion activity centers are modeled as an inhomogeneous point process wherein the density of activity centers in a particular grid cell varies in association with values of the previously-developed statewide mountain lion resource selection function (Robinson et al., 2015). This approach was previously shown to improve inference on mountain lion density in this system (Proffitt et al. 2015b).

We have modified and continued development of the previous model in two ways. First, we migrated the analyses from SCRBayes (Russell et al., 2012), a Bayesian-based framework, to the recently developed oSCR (open Spatial Capture-Recapture) (Sutherland et al. 2017) package in R (R Core Team 2017). Compared to SCRBayes, oSCR has the advantage of speed and ease of implementation for users that are not familiar with Bayesian inference. To meet our needs, we modified the oSCR code to produce a series of routines specific to this mountain lion dataset. Second, 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. We modified the model to simultaneously estimate space use of male and female mountain lions using both the spatial capture-recapture data and telemetry data. 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 (oSCR), as well as the revised code with the addition of telemetry information, to compare to previously published estimates for 2012-2013.

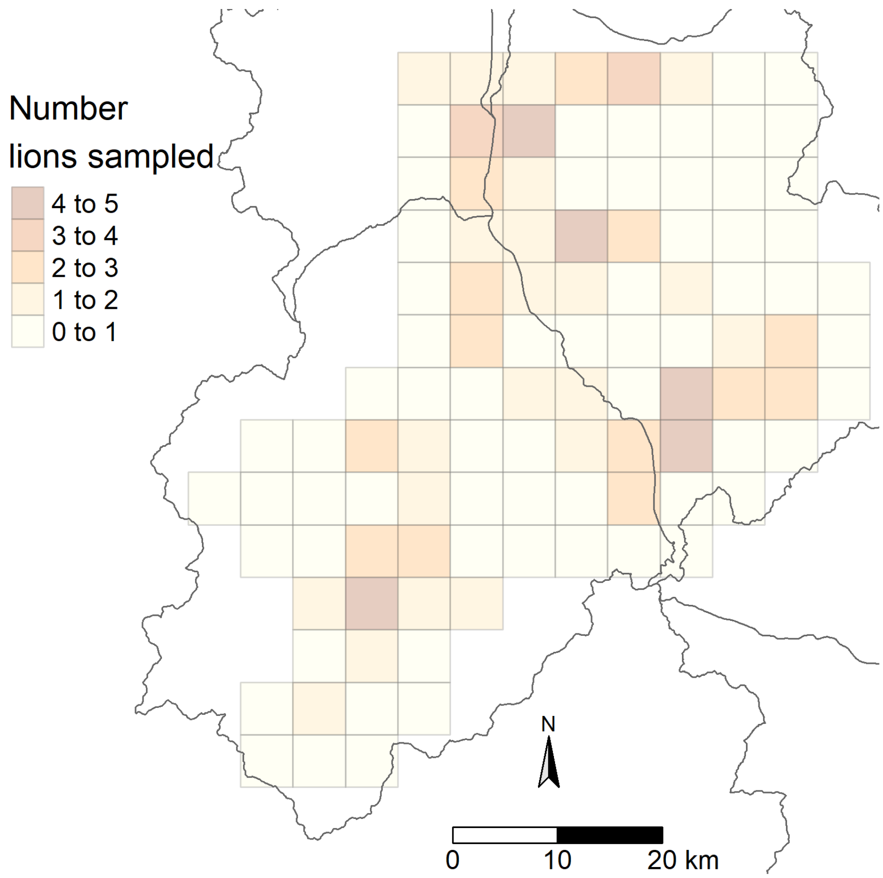

Figure 2.3. *Number of mountain lions sampled by either the organized search effort or harvest in each of the 105 5 km x 5 km grid cells during the entire sampling period (December to April) in 2016-2017. A total of 54 unique individuals were identified, 14 of which were sampled only from harvest.*

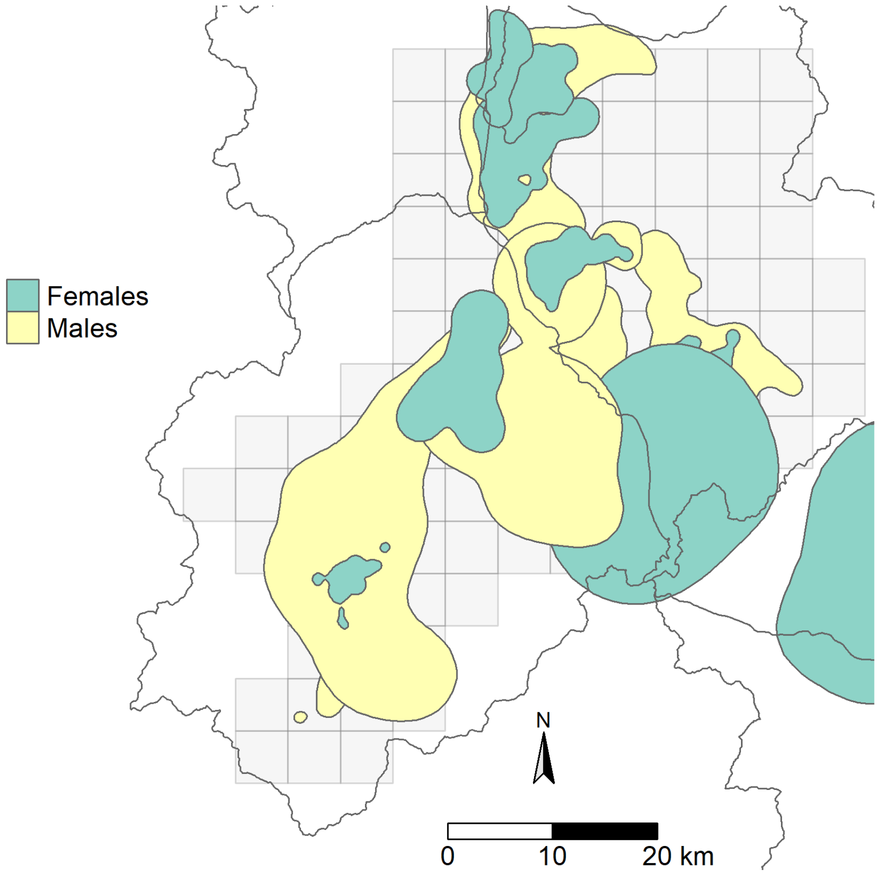

Figure 2.4. *Kernel density estimators (95%) fit to the telemetry data from 14 individual mountain lions (6 males and 8 females) collared during the 2016-2017 sampling period. On average, males have significantly larger activity ranges than females.*

To compare the space use parameters estimated from our top model with space use data collected from radio collars, we calculated a 95% kernel density estimate for the winter range (December to March) of each individual to provide a separate estimate of activity ranges for males and females (Figure 2.4). The median activity range for males was estimated to be 208.4 km^2 (95% CI: 115.8, 245). For females, the median activity range was estimated to be 50.9 km^2 (95% CI: 19.3, 799.5). For the spatial capture-recapture model, the telemetry record for each individual was sub-sampled to one location per day, resulting in a total number of fixes for each collar that ranged from 33 to 108.

For the spatial capture-recapture analysis, we fit a single model with the following structure:

1. density of lions has a baseline value ($\beta_0^{Density}$), which then varies in association with the mountain lion RSF ($\beta_{RSF}^{Density}$),
2. detection by the organized search effort has a baseline probability of detection ($\beta_0^{Detection}$), which varies for male mountain lions ($\beta_{Male}^{Detection}$) and as a function of the logarithm of the effort in each grid cell ($\beta_{Effort}^{Detection}$),
3. space use varies according to sex ($\sigma_{Male}, \sigma_{Female}$),

Telemetry information from collared individuals can provide a substantial amount of information on how individuals use space, potentially improving our understanding of the parameters related to space use ($\sigma_{Male}, \sigma_{Female}$). It is straightforward to use a multinomial likelihood wherein the probability of being in a statespace pixel shares the same structure as the spatial capture-recapture framework as well as the sex-specific sigma parameters ($\sigma_{Male}, \sigma_{Female}$). Thus, we added a fourth component to the model:

4. telemetry information was incorporated to help estimate the space-use parameters ($\sigma_{Male}, \sigma_{Female}$),

Parameter estimates from this model (Table 2.3) indicate that the probability of detection increases in association with search effort, and weakly suggests that the decline in the probability of detection with distance differs for males and female (Figure 2.4). The density of mountain lion activity centers increases in areas with high RSF values, consistent with previous work in this study area (Proffitt et al., 2015b). Space-use was different for males and females: the space use parameters ($\sigma_{Male}, \sigma_{Female}$) translate into male activity ranges with a median of 400.7 km^2 (95% CI: 340.8 to 501.3 km^2) and female activity ranges with a median of 180.5 km^2 (95% CI: 160.4 to 200.7 km^2).

Table 2.3. *Parameter estimates from the best model that incorporates variability in activity centers in relationship to values of the mountain lion RSF, separate detection processes for the organized search effort and hunter harvest, and the incorporation of telemetry data.*

	Density		***Detection***			***Space use***		***Sex ratio***
	(log scale)		(log scale)			(log scale)		(logit scale)
	$\beta_0^{Density}$	$\beta_{RSF}^{Density}$	$\beta_0^{Detection}$	$\beta_{Effort}^{Detection}$	$\beta_{Male}^{Detection}$	σ_{Male}	σ_{Female}	φ_{Male}
mean	-0.684	0.87	-3.46	0.55	-0.12	-0.65	-0.89	-0.94
sd	0.29	0.238	0.59	0.13	0.44	0.02	0.01	0.39

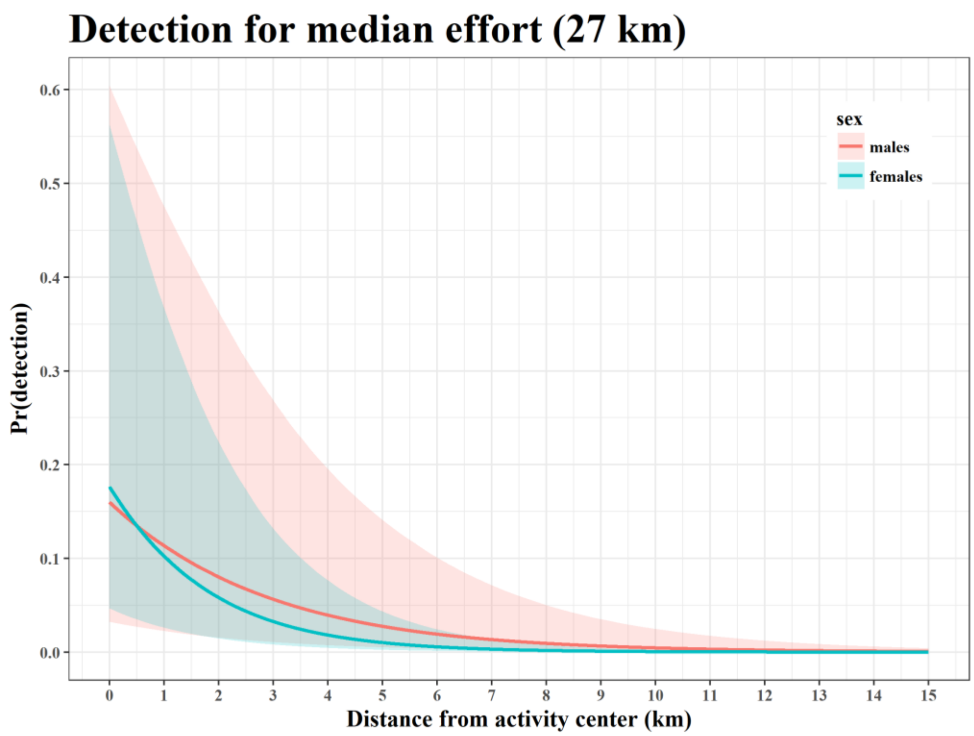

Figure 2.4. *The probability of detection as a function of distance from activity centers for the median effort (27 km of searching) from the 2016-2017 sampling period.*

Using this model, we estimated a median density of 2.5 mountain lions per 100 km^2 (95% CI: 1.7 to 3.8) across the entire state space (6,184 km^2). Estimated densities showed strong spatial asymmetry (Fig 2.6), which is consistent with a strong relationship between density and values of the mountain lion RSF. Using the estimated densities per pixel, we extracted estimates of abundance and density for the trapping area, and hunting districts 250 and 270 (Table 2.4). We estimated the proportion of males in the population as 0.29 (95% CI: 0.15 to 0.47).

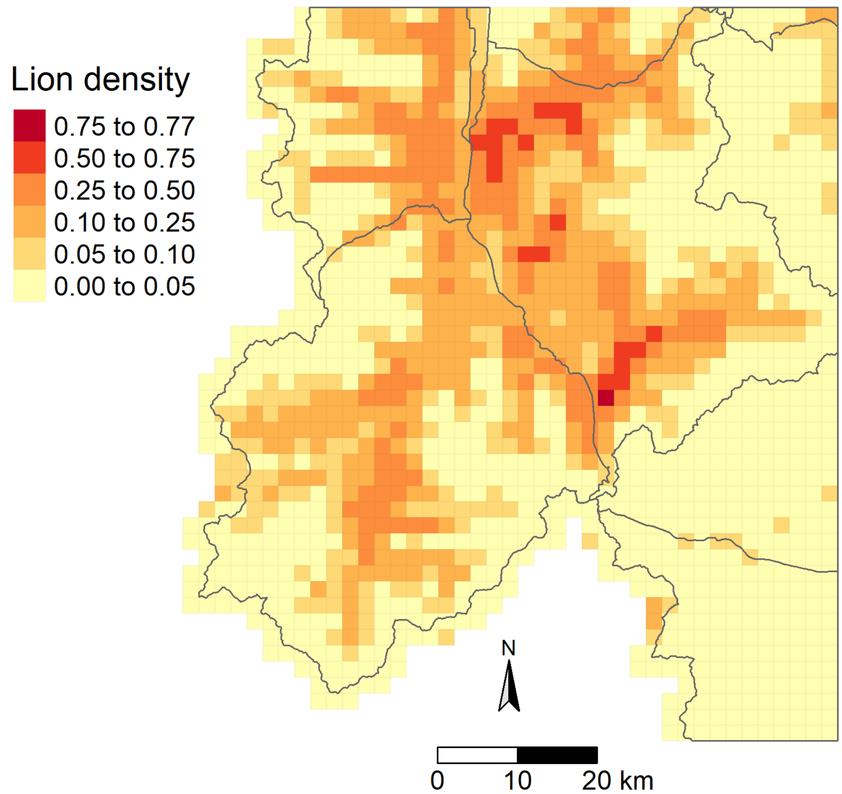

Figure 2.6. *Estimated number of mountain lion activity centers in each 2 km x 2 km state space pixel. The results correspond to an estimated aggregate density of 2.5 lions per 100 km^2; however, the spatial distribution of activity centers and density values are related to values of the mountain lion RSF and vary considerably across the landscape.*

Table 2.4. *Comparison of estimated median densities (mountain lions per 100 km^2) and abundances (N), with 95% confidence intervals. For 2012-2013, we report the published estimates (Proffitt et al. 2015b), the revised estimates using new code, and revised estimates that include telemetry information. For 2016-2017, we report estimates based on the revised code that includes telemetry information.*

		2012-2013			2016-2017
		Published	Revised model	Revised model, with telemetry	Revised model, with telemetry
Study Area	$\hat{N}$	**226**	**215 (147, 354)**	**223 (138, 377)**	**155 (106, 232)**
	$\widehat{density}$	**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)**
	$\widehat{density}$	**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)**
	$\widehat{density}$	**5.2 (3.4, 9.1)**	**5.4 (3.7, 8.9)**	**5.5 (3.5, 9.6)**	**4.3 (3.2, 6.1)**

Finally, we compared the estimated spatial density of mountain lions in the 2016-2017 period to that estimated using the revised model with telemetry from the 2012-2013 data (Figure. 2.7). Estimated changes in the densities of mountain lion activity centers vary spatially and have generally decreased since 2012-2013. However, confidence intervals around density estimates overlap, and a formal analysis regarding effects of harvest management on mountain lion density will be completed in 2019.

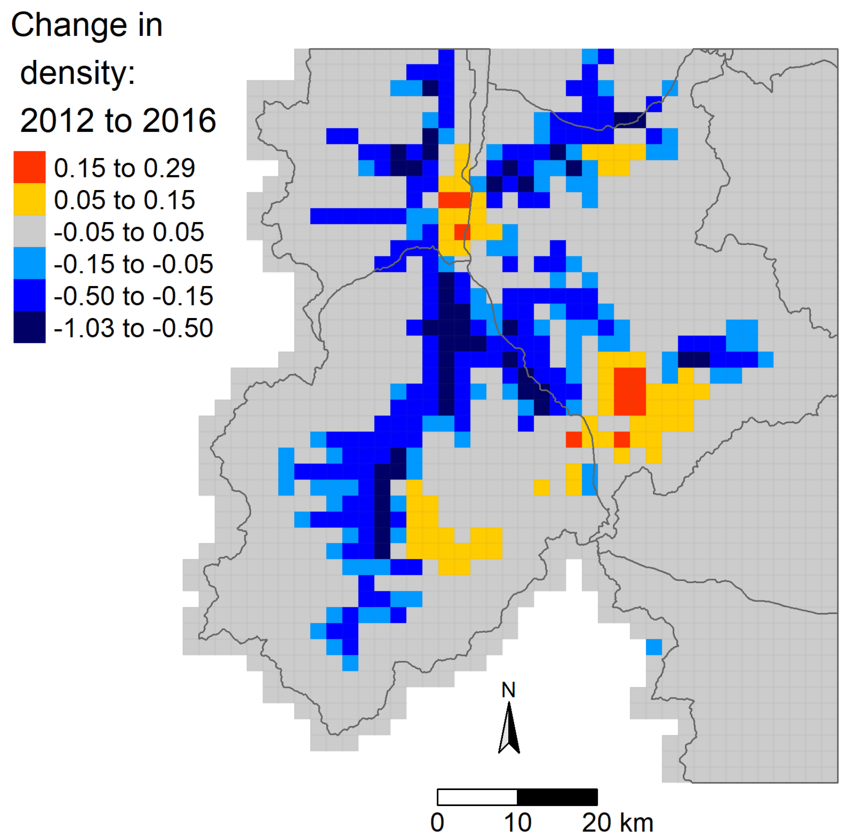

Figure 2.6. *Difference in estimated density of mountain lions in each 2 km x 2km grid cell from 2012 to 2016 (positive values indicate increase in mountain lion densities from the 2012-2013 season to the 2016-2017).*

2.3 Mountain lion population estimation in the Upper Clark Fork area, 2017-2018

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 currently still underway and will continue until March 31, 2018.

Objective #3: Evaluate the effects of wolf harvest management regulations on wolf harvest and population density.

Prior to 2011, wolves in the Bitterroot Valley were part of the experimental non-essential population that resulted from the reintroduction of wolves into the Central Idaho Experimental Area in 1995-96. In May 2011, wolves in Montana became subject to state management authority guided by the Montana Wolf Conservation and Management Plan. Across Montana, minimum wolf counts increased steadily until 2011. Since 2011, the statewide minimum counts and population estimates have been stable to declining, which is at least partially due to decreased effort to identify all wolves, and local population abundance varies annually with harvest management goals, management of livestock-wolf conflict, and other biological factors (Coltrane et al. 2016).

As part of the west-central Montana integrated carnivore-ungulate management plan to reduce carnivore densities, wolf harvest management prescriptions were implemented in the south Bitterroot study area to reduce wolf population densities. Our objectives are to evaluate the effects of wolf harvest management regulations on realized wolf harvest and population density in the south Bitterroot study area.

3.1 Wolf harvest regulations and harvest

Between 2008 and 2011, wolves in Montana were delisted, relisted, and then delisted again (Hanauska-Brown et al. 2011). 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 MFWP 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 MFWP. We used hunter and trapper reports to track the number of wolves harvested annually from mandatory reporting records (Table 2.3).

Table 2.3 *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

3.2 Wolf population estimation

MFWP uses a combination of radio-collaring efforts, direct observational counts, remote cameras, and track surveys to annually track the wolf population, document pack size and breeding pair status of known packs, and determine pack territories in our study area. Ground and aerial tracking occurs 1-2 times per month to locate VHF and GPS collared animals and count the number of wolves travelling together. Additional information on sightings, breeding activity, mortalities, and human-wolf conflicts is collected throughout the year. This information is used to estimate the minimum count of wolves per hunting district on December 31st of each year (Coltrane et al. 2016).

In 2000, MFWP 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 (Table 2.4).

Table 2.4 *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

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