Ecology of Cougars (*Puma concolor*) in north-central Montana:

Distribution, resource selection, dynamics, harvest, and conservation design

Chippewa Cree Tribal Wildlife Program

In cooperation with

World Wildlife Fund
Northern Great Plains Program
Bozeman, Montana

Final Report April 2012

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1. Introduction

Increasing attention is being directed to ecological restoration in North American grasslands (Forrest et al. 2004), particularly with respect to species that have been lost or eliminated from these systems. Some species, notably wolf (*Canis lupus*), bear (*Ursus* spp.), and cougar are expanding in Montana through reintroductions and natural recolonization. While the value of large carnivores to ecosystem function is increasingly understood (Terborgh et al. 1999; Pyare and Berger 2003; Smith et al. 2003; Soule et al. 2003, Ripple and Beschta 2006, Dalerum et al. 2008, Licht et al. 2010, Estes et al. 2011, Ritchie et al. 2012), large carnivores present major challenges and opportunities for communities, ranchers, and wildlife managers because they may also kill livestock or reduce ungulate populations in landscapes where they have been absent in recent history (Atwood et al. 2007, Atwood et al. 2010, Griffin et al. 2011). Because large carnivores operate at multiple and large scales (Kunkel et al. 2012), management, conservation, and restoration of top carnivores have played a significant role in fostering ecosystem approaches to wildlife management (Minta et al. 1999).

Cougars have recolonized much of central and eastern Montana. Much of the landscape in north-central Montana appears suitable for recolonization (Riley and Malecki 2001). Prey populations are robust and there are large contiguous areas of undeveloped land. The area contains the largest block of protected and public lands in the Great Plains (e.g. Charles M. Russell National Wildlife Refuge (CMR) and adjacent Upper Missouri Breaks National Monument (UMB-NM), as well as several million acres of Bureau of Land Management lands and a diverse mix of potentially suitable habitats. It is important to understand and document how cougars are using the landscape as they recolonize it, because that will provide much insight into conservation strategies for this species, their prey and what might occur as other carnivores expand into the region (Mladenoff et al. 1999). Presently there is no regional, multi-jurisdictional conservation plan for cougars in eastern Montana. General objectives for cougar management by Montana Fish, Wildlife, and Parks (FWP) are to manage populations at a level that promotes social and political tolerance, minimizes human/cougar conflicts while ensuring viable cougar populations, and sustained recreational opportunity.

Information about cougar recolonization and ecology of established populations will greatly enhance understanding and management of cougars in the grasslands and prairie breaks of north-central Montana. This is especially important because cougars have been little studied in this type of landscape (Williams 1992) and very little work has been conducted anywhere on a recolonizing cougar population. Montana FWP (1996) has adopted a cougar management program (including harvest) that uses regional management based on habitat capabilities of respective regions, and the CMR is developing harvest management guidelines as part of its ongoing planning processes. But because very little is known about capabilities of landscapes in this region to support cougars, or how to design and manage populations in source-sink landscapes to ensure persistence of cougars and other large carnivores (Woodruff and Ginsberg 2000, Carroll et al. 2002, Ruth et al. 2011), additional information on cougar ecology, threats, and habitat use is needed.

First, data are needed to understand if and how the cougar population in north-central Montana is expanding, if it will be viable over the long term in this region, and what management is required to ensure it remains viable. To provide appropriate management, we need to determine if and how this population is connected to other cougar populations (Beier 1996; Sweanor et al. 2000; Laundre and Clark 2003), to other source populations, where the sources and sinks are (Doak 1995, Sweanor et al. 2000, Robinson et al. 2008, Ruth et al. 2011) and how we ensure it remains a functional part of the larger statewide cougar meta-population (Haight et al. 1998). Addressing these questions will also provide information about connectivity in the region for other species and can add significant information about management needs to ensure this connectivity potential remains intact (Boyd and Pletscher 1999; Craighead et al. 1999).

Second, as wildlife managers move to more sophisticated models of cougar harvest as opposed to general seasons (unlimited harvest of either sex), they will need to have information on which to base harvest levels. Limited entry (harvest is limited by restricting the number of licenses sold), quota system (harvest is limited by season closure once a prescribed number of animals are taken) and “zone management” (Logan and Sweanor 2001) or "meta-population" model (Laundre and Clark 2003) strategies are thought to reduce the risk of overharvest by ensuring a sustainable loss of the total population (limited entry), reduction of female mortality (quota system), or preservation of source populations that sustain hunted areas (meta-population model).

Developing information on cougar resource selection will provide a better understanding of population potential in grassland and breaks systems. At the very least, more information on factors affecting sustainability of harvest in general based on regional conditions would be useful, particularly in regions with low cougar densities and connectivity, and would be a very valuable contribution in designing regional harvest management.

2. Project Goals & Objectives

Overall Goal

Understand cougar population dynamics, habitat use, and distribution to assess needs for large carnivore conservation in a prairie landscape in a multi-jurisdictional setting.

Objectives

1. Obtain a minimum count estimate of cougars within the project area and factors influencing this, including harvest, and landscape components and configuration;

2. Obtain estimated rate of cougar mortality, as well as cougar density, population distribution, and reproduction;

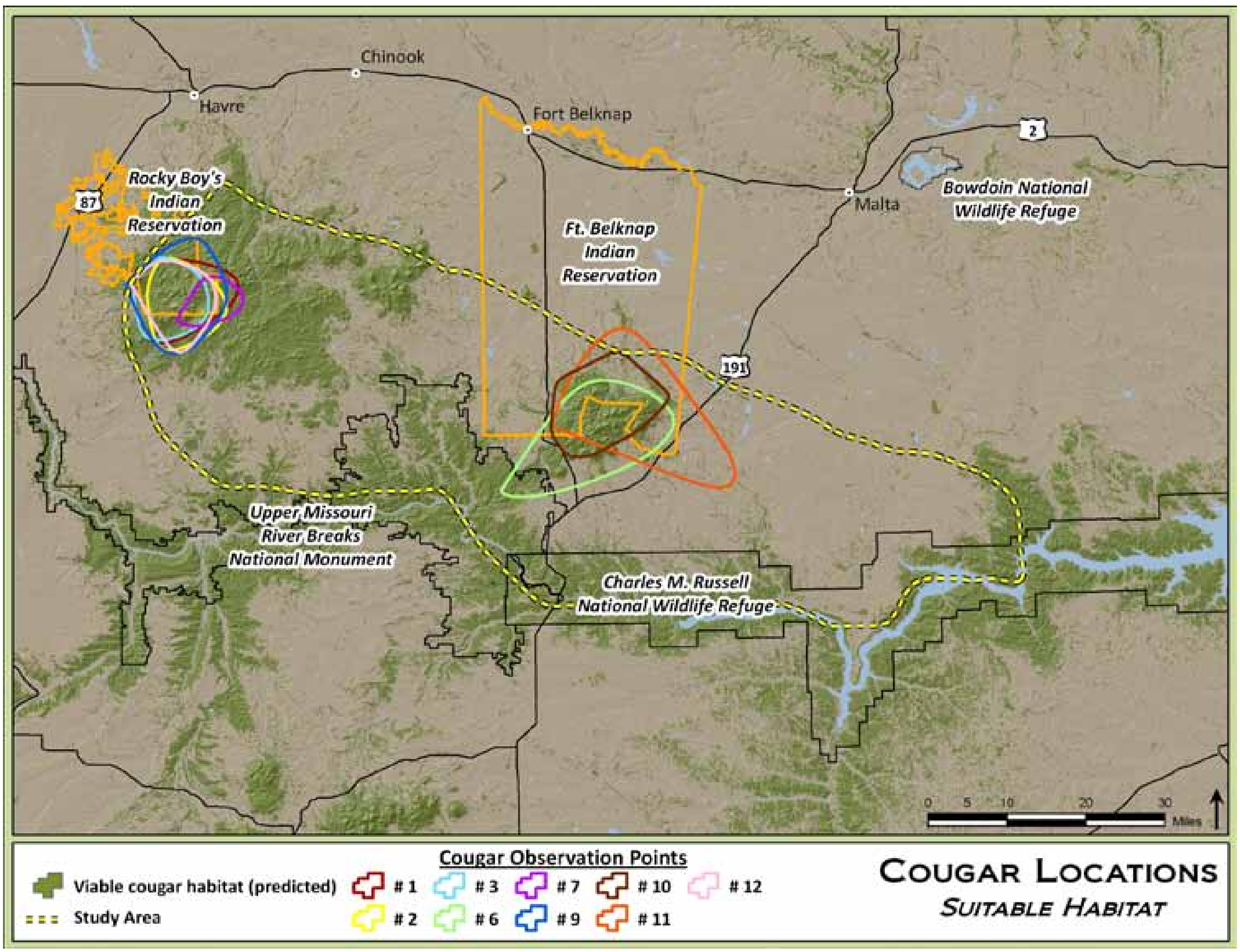


Figure 1. Home range minimum convex polygons for GPS-collared cougars on and around Rocky Boy's and Ft. Belknap Indian Reservations overlayed on cougar habitat suitability index developed by Riley and Malecki (2001).

3. Obtain estimates of size and composition of cougar home ranges and habitat use;

4. Determine the role of the Little Rockies and Bears Paws as a potential source population and factors influencing this including connectivity between these ranges and the Missouri River Breaks and other nearby habitats;

5. Obtain estimates of overlap and potential for conflicts between cougars and livestock and prescriptions to reduce conflicts.

3. Study Area

The Rocky Boy's and Ft. Belknap Indian Reservations are located in north-central Montana (Figure 1). The reservations include a variety of terrain ranging from 1,000 – 2,300 m including the Bears Paws Mountains, Little Rockies Mountains, foothills, mixed-grass prairie, coniferous and mixed-coniferous/deciduous forests, and wetlands. The project area encompasses approximately 7,000 km^2 (Figure 1).

The Bears Paws and Little Rockies are large volcanic mountain chains, sky islands in the eastern Montana prairie and rated as "high" for biodiversity (The Nature Conservancy 1999). We know of no wildlife research ever conducted in either of these ranges. Rocky Boys has recently reintroduced bighorn sheep (*Ovis canadensis*) to the Bears Paws.

The area outside the mountains is characterized by level to rolling plains in the north trending to deeply dissected and rugged topography near the Missouri River in the south. Western wheatgrass (*Agropyron smithii*) grasslands and big sage (*Artemesia tridentada*) shrublands dominate the level to rolling plains. Greasewood (*Sarcobatus vermiculatus*) shrublands are located on soils with concentrated salts in uplands and in claypans. Breaks along the Missouri are dominated by bluebunch wheatgrass (*Agropyron spicatum*) grasslands and low elevation coniferous forest/woodlands. Prey species for cougars include white-tailed deer (*Odocoileus virginianus*), mule deer (*Odocoileus hemionus*), bighorn sheep, elk (*Cervus elaphus*) and beaver (*Castor canadensis*) at varying densities across the region. No other large carnivores are present.

4. Methods

We used GPS radio collars to determine cougar mortality and movements (Beier 1995, Kunkel 1997, Kunkel et al. 1999, Sweanor et al. 2000, Anderson and Lindzey 2003). We either captured cougars using hounds released on tracks or by snares (Kunkel et al. 2007). We immobilized captured cougars and then fitted them with a radio collar. We located cougars via aerial telemetry to detect mortality and dispersing or wide-ranging animals. Collars were equipped with mortality sensing devices in order to measure cougar mortality rates and causes and factors influencing mortality. We recorded hunter harvest of uncollared animals. We computed survival and cause-specific mortality rates via the program MICROMORT (Heisey 1985, Heisey and Fuller 1985). We considered intraspecific strife to be the cause of death when blood, subcutaneous hemorrhaging at wound sites, or signs of a struggle were found at the site. We compared daily survival rates for each interval by examining overlap among confidence intervals, pooling data from intervals if rates were not significantly different (Heisey and Fuller 1985). We assumed that signal loss from radio collars after the expected 2-year life of the battery had resulted from battery failure.

We recorded number of kittens we located with females.

Resource Selection

We uploaded GPS locations for each cougar into point shapefiles in ArcMap 9.3 (ESRI 2008). We error checked data and removed invalid points (e.g., those recorded after an animal was harvested). We used the remaining points to create a home range minimum convex polygon using the Hawth's Tools Animal Movement extension (Beyer 2004). We created polygons that were overlayed on previously developed models of suitable cougar habitat (Riley and Malecki 2001, Figure 1) and important landscape attributes (i.e., vegetation, slope; Table 1, Figures 2 and 3) to examine resource selection by cougars .

Model Training

We divided the data by area (Bears Paws, Little Rockies, CMR), reserving all Little Rockies and CMR data for model validation (see validation below). We developed winter resource selection function models (RSF) following Manly et al. (2002) for male and female cougars separately as well as for both sexes combined. RSFs evaluate resource selection by com-

Table 1. Terrain and landcover GIS layers (candidate variables) used in predictive RSF models for mountain lions in Montana.

Variable	Variable Type	Range of Values	Description
Topography			
North	Categorical	0,1	North aspects from 315° to 45°
South	Categorical	0,1	South aspects from 135° to 225°
East	Categorical	0,1	East aspects from 45° to 135°
West	Categorical	0,1	West aspects from 225° to 315°
Flat	Categorical	0,1	No aspect (slope = 0)
Slope	Continuous	0–6827%	Percent slope (equivalent to 0 – 90°)
Elevation	Continuous	201-3897m	Elevation in meters
Landcover			
Agriculture	Categorical	0,1	Pasture and cultivated crops
Barren	Categorical	0,1	Disturbed barren land
Developed	Categorical	0,1	Human development of varying intensity
Forest	Categorical	0,1	Deciduous and coniferous forest
High Montane	Categorical	0,1	Alpine areas above treeline
Introduced Veg	Categorical	0,1	Introduced vegetation
Semi Desert	Categorical	0,1	Semi-desert scrub and dry grassland
Shrubland	Categorical	0,1	Grassland and shrubland
Transitional Vegetation	Categorical	0,1	Recently burned, logged, and regenerating areas.
Water	Categorical	0,1	Water
Distance to Forest Cover	Continuous	201-3897m	Linear distance to forested landcover
Distance to Development	Continuous	201-3897m	Linear distance to developed landcover

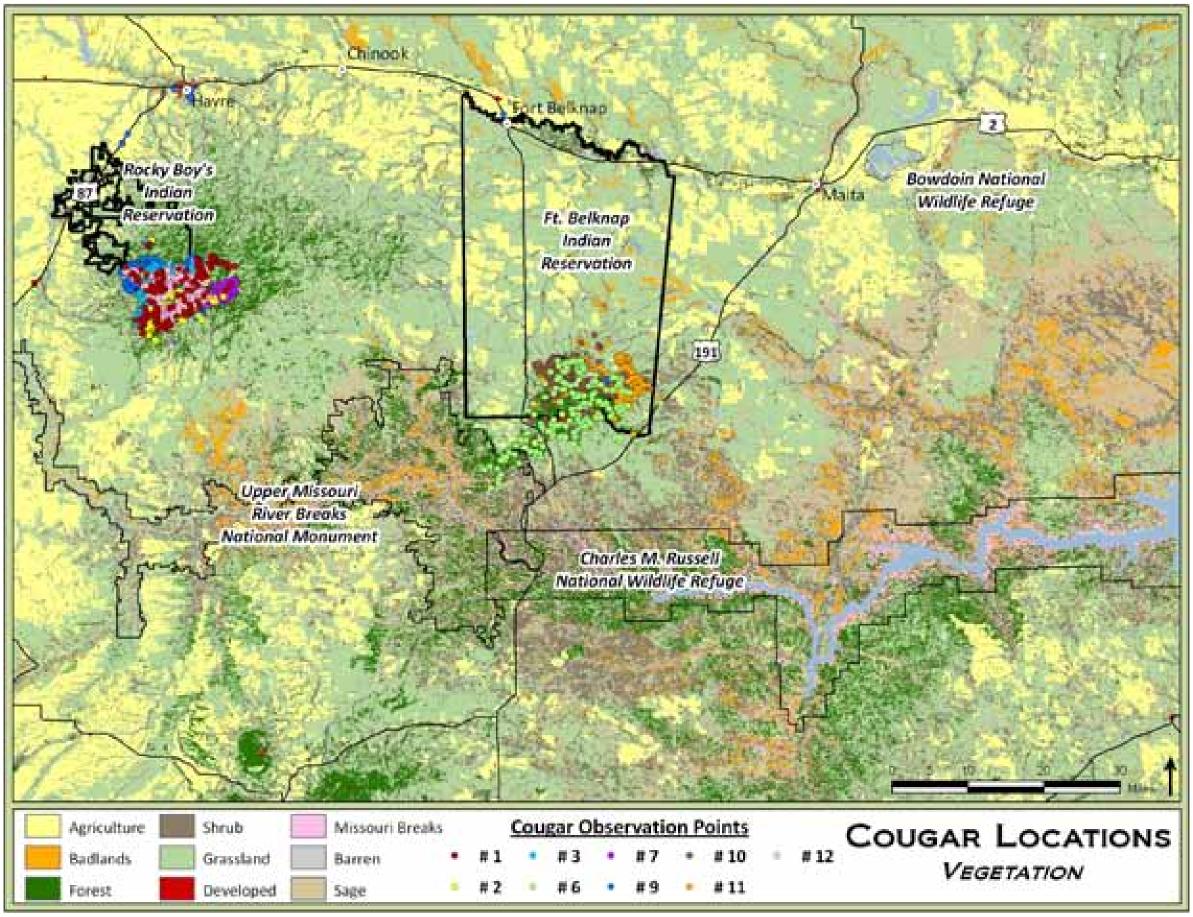
paring the proportionate use of resources relative to their proportionate availability using logistic regression making the selection of available habitat instrumental in proper model parameterization (Hosmer and Lemeshow 2000, Manly et al. 2002). We used 3 level generalized linear mixed-effects modeling (GLLAMM) under a logistic regression framework to account for unbalanced sample size between individual radiocollared animals, varying resource availability between population segments, and to account for the individual animal as the most appropriate sample unit (Gillies et al. 2006, Bolker et al. 2009). The form for a generalized 3-level mixed-effects model for location i, animal j, and study area k, with a random intercept is:

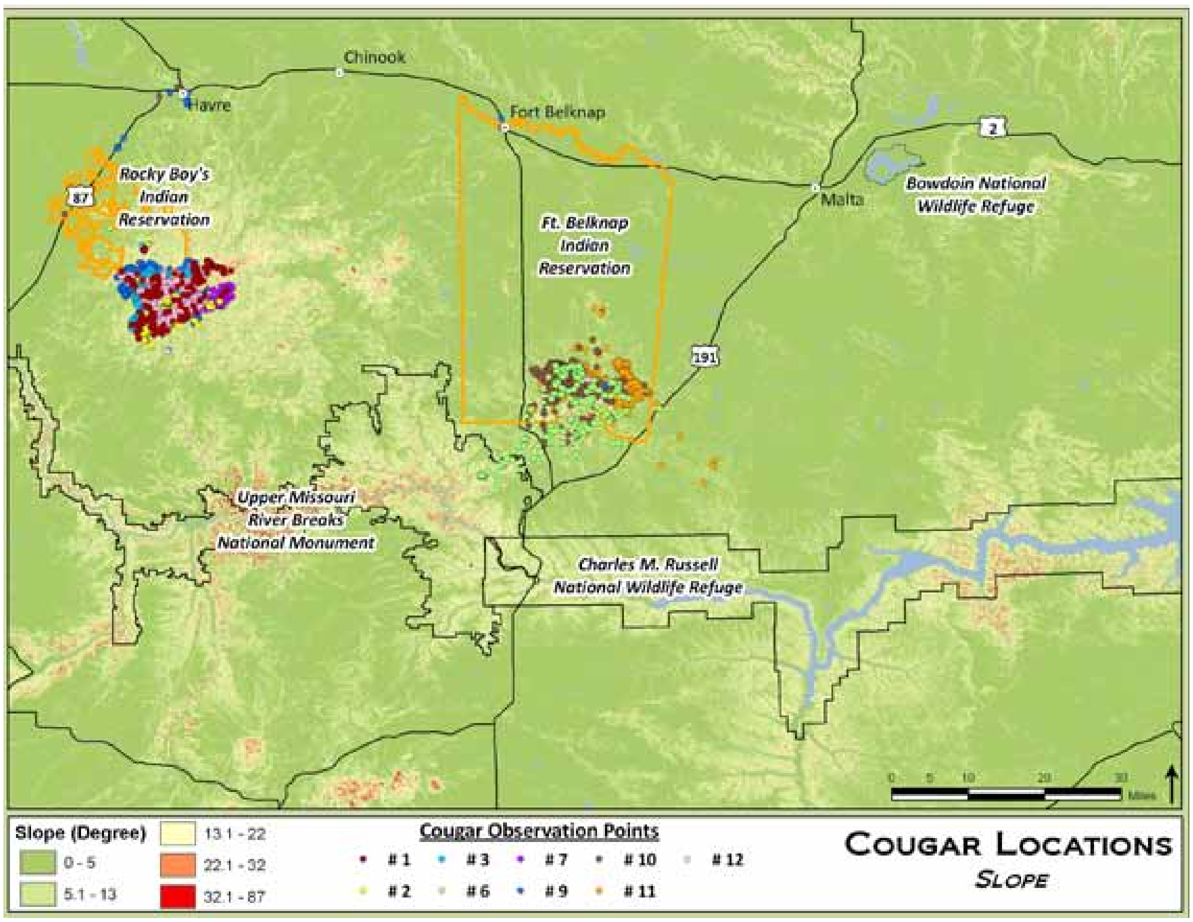
$$\text{Logit}(y_{ijk}) = \beta_0 + \gamma_{jk}^{(animal)} + \gamma_{k}^{(study)} + ... + X\beta + \varepsilon_{ijk}$$

(equation 1)

where β_0 is the fixed-effect intercept, $\gamma_{jk}^{(animal)}$ and $\gamma_k^{(study)}$ are the random variation in the intercept at the animal and study area levels, Xβ is the vector of the fixed-effect resource selection coefficients for covariate x_{ijk} and ε_{ijk} is unexplained residual variation. Our notation for random effects follows Rabe-Hesketh and Skrondal (2005, pp. 236) and Gillies et al. (2006). Winter, December 1st to April 15th, RSFs only were produced as population estimates below are based on winter collaring programs.

We considered a suite of spatial resource or 'habitat' covariates in development of resource selection function models. We overlaid cougar telemetry data on a suite of raster layers (30 meter resolution) in a geographic information system (GIS) to quantify the underlying habitat associated with each location. Habitat variables could be loosely categorized as landcover (i.e. dominant vegetation) topographical (i.e. elevation) (Table 1). Landcover categories were based Gap Analysis Program level 1 (US Geological Survey 2010).





Figures 2 (Top) and 3 (Bottom). Cougar GPS locations overlayed on important landscape attributes, vegetation and slope, to visually evaluate how cougar distribution patterns are influenced by the landscape.

We used a manual stepwise model building method described by Hosmer and Lemeshow (2000) to create "best" models that described the resource selection of cougars. This pluralistic model building approach best reflects the balance between prediction and mechanism as achieved through regression-type models (Stephens et al. 2005). Candidate variables were considered if biologically relevant, ecologically plausible, non-confounded, and uncorrelated at a correlation coefficient of |r| <0.5 (Hosmer and Lemeshow, 2000). We considered both linear and non-linear (quadratic) responses to continuous variables and used a combination of graphical and Akaike information criteria (AIC) based methods to determine how a response was best modeled. First, frequency histograms of used and available distance locations were plotted then compared to the predicted values of a univariate model to graphically depict each species' response. Secondly, the AIC values of univariate models fit as a linear and quadratic response were compared in order to gauge if modeling as a quadratic improved fit (Burnham and Anderson, 1998). We followed the same procedure for all continuous covariates in which we expected potential non-linear resource selection patterns (i.e. selection for intermediate levels), including elevation, slope, distance to human activity, distance to forest.

Model Validation

The most important measure of model fit for habitat or resource selection models is predictive capacity, or how well the model predicts new observations (Boyce et al. 2002). We used both within-sample and out-of-sample validation techniques to test the predictive ability of our models. Within-sample validation first consisted of standard logistic regression diagnostics and goodness-of-fit measures (Fielding and Bell 1997). We tested our models for multicollinearity using variance inflation factors (VIFs). Individual variables that are completely uncorrelated have VIF values of 1. Individual parameters with VIF scores greater than 10 were removed as candidate variables, and all models were tested to ensure that mean scores were not considerably larger than 1.0 (Hosmer and Lemeshow 2000; Menard 2002). Classification tables where used to assess the models ability to correctly cross-classify locations as used (sensitivity) or available (specificity). Area under the receiver operating characteristic (ROC) curve was calculated for each model. Generally ROC scores of >0.7 are considered acceptable levels of discrimination between locations while scores >0.8 are considered excellent (Hosmer and Lemeshow 2000). We used k-fold cross-validation where 5-random subsets of the data are validated with a model built from the remaining 80% of the data. If the RSF model predicts habitat use well, then there should be a strong Spearman's rank correlation (rho) between predicted use and ranked habitat categories (e.g., from 1 to 10). A Spearman's rank correlation of >0.64 indicates that the model has good predictive ability (Fielding and Bell 1997; Boyce et al. 2002).

The amount of data we obtained afforded us the ability to use out of sample validation, which arguably provides the best measure of a model's ability to predict resource use correctly (Fielding and Bell 1997). All VHF data collected and approximately half of the GPS collar data where reserved as an out of sample data set (i.e. not used in model training). We evaluated predictive performance similar to the k-folds procedure using the Spearman rank correlation between the predicted amount of out of sample usage and ranked habitat categories (Boyce et al. 2002). Finally, as we were predicting resource use across the entire state including areas where no telemetry data had ever been collected, we used harvest locations as a second form of out of sample validation.

We ran a moving window over the project area screening out habitat that did not have a high enough RSF value to support a resident female within an area of a single home range.

5. Results

Annual Summary

Winters 2006/2007 and 2007/2008

We spent 30 days in the field searching for cougar tracks and we collared 5 cougars on Rocky Boys and 2 on Ft. Belknap (Table 2). Four of these cougars were harvested and 1 was "probably harvested" based on the data from a cougar we collared (#3, Table 2) that showed she had an established home range that overlapped the location where an adult female was harvested on the RB reservation in December 2008. This female had 3 kittens with her when she was captured and collared. Harvest of male cougar #5 was verified from blood samples we obtained from this individual

Table 2. Date, ID, location and status of cougars collared, winter 2006/2007 and 2007/2008.

Date collared	Cougar #	Age/Sex	Location	Status
12/2006	1	Adult Male	Sandy Creek, Bears Paws	Harvested, 2/2007*
12/7/2007	2	Adult Male	Eagle Creek, Bears Paws	Harvested, 1/2009*
12/12/2007	3	Adult Female	Lost Canyon, Bears Paws	Probable harvest 12/2008
1/25/2008	4	Subadult Female	Beaver Creek, Little Rockies	Missing
2/1/2008	5	Adult Male	Bailey Mtn., Bears Paws	Harvested 2/2009
2/14/2008	6	Adult Male	Bear Gulch, Little Rockies	Recollared 10/23/08*
3/31/2008	7	Adult Female	Baldy Mountain, Bears Paws	Natural Mortality 7/2008*

**collar retrieved and downloaded*

Table 3. Date, ID, location and status of cougars collared during 2008/2009.

Date collared	Cougar #	Age/Sex	Location	Status
10/23/2008	6	Adult Male	Lodgepole Creek, Little Rockies	Harvested 1/2009*
12/17/2008	8	Subadult Male	Lower Sandy Creek, Bears Paws	Harvested 12/8/09
2/3/2009	9	Adult Male	Beaver Creek, Bears Paws	Harvested 3/11/09*
3/31/2009	10	Adult Female	Browns Canyon, Little Rockies	Natural Mortality 12/2009*
4/2/2009	11	Adult Female	Big Warm, Little Rockies	Harvested 10/2009*
5/31/2009	12	Subadult Male	Beaver Creek, Bears Paws	Recollared 10/30/09*

**collar retrieved and downloaded*
Note: Male cougar # 6 was recollared on October 23, 2008 on the Fort Belknap Indian Reservation.

that allowed us to match DNA from an individual harvested in the Bears Paws (Table 2).

Winter 2008/2009

We spent 27 days in the field searching for cougar tracks, 23 days on Rocky Boys and 4 days on Ft. Belknap, and snared for 190 trap nights during summer and fall 2009. We caught 9 cougars, including 3 kittens, and collared 2 of the adults on Rocky Boys (one by foot snare - #12) and 3 (one by foot snare -#13; Table 3) on Ft. Belknap.

Hunters killed 9 cougars in the Bears Paws during the 2008/2009 hunting season (Table 4). Eight of the 9 cougars killed were males (6 adults, 2 subadults). Five adult males and 1 subadult male were killed off of the reservation. Three cougars were harvested on the Rocky Boys including an adult male, an adult female, and a subadult male (Table 4). Another adult male (# 6) was harvested on public land near the Little Rockies and another cougar was killed in a private trap in the Missouri Breaks.

Winter 2009/2010

We spent 28 days in the field searching for cougar tracks, 18 days on Rocky Boys and 10 days on Ft. Belknap. We captured and recollared #12 in October 2009 on Rocky Boys (Table 5). The male was harvested adjacent to the Rocky Boys in December 2009. We captured and radiocollared #13 in the LR in October 2009. We suspect she was harvested in December 2009.

Table 4. Date, age, sex and location of cougars harvested by hunters in FWP Region 6 during 2008/2009 season.

Date of Harvest	Age	Sex	Collared cougar #	Location of Kill
December 2008	Adult	Female	3	Sandy Creek, Rocky Boy's
December 2008	Subadult	Male		Sandy Creek, Rocky Boy's
December 2008	Adult	Male		Eagle Creek, Rocky Boy's
January 2009*	Adult	Male	6	Thornhill, Butte BLM
January 2009	Subadult	Male		Eagle Creek, Private
January 2009	Adult	Male	2	Eagle Creek, Private
February 2009	Adult	Male	5**	Eagle Creek, Private
March 2009	Adult	Male	9	Eagle Creek, Private
March 2009	Adult	Male		Eagle Creek, Private
April 2009	Adult	Male		Baldy Mtn., Private

Note: Another collared male (#1) was harvested on private land in Eagle Creek in February 2007.
** Harvest date was either December 2008 or January 2009.*
***see Table 1.*

Table 5. Date, ID, location and status of cougars collared during 2009/2010.

Date collared	Cougar #	Sex	Location	Status
10/4/2009	13	Adult Female	Bear Gulch, Little Rockies	Suspected harvest
10/30/2009	12	Adult Male	Lost Canyon, Bears Paws	Harvested 12/2009*
5/8/2010	14	Subadult Male	Green Creek, Bears Paws	Collar dropped* 7/10/10

**collar retrieved and downloaded*

Table 6. Date, age, sex and location of cougars harvested by hunters in north central Montana during. 2009/2010 season.

Date of Harvest	Age	Sex	Cougar ID	Location of Kill
October 2009	Adult	Female	#11	Near Hays, FBIR
November 2009	Subadult	Female		Near Hays, FBIR
December 2009	Adult	Male	#8	Lodgepole Cr., FBIR
December 2009	Adult	Female		McConnel Mtn., FBIR
December 2009	Subadult	Male		Near Lodgepole, FBIR
December 2009	Subadult	Female		Near Zortman, BLM
December 2009	Subadult	Male		Near Zortman, BLM
December 2009	Adult	Female		Indian Butte, FBIR
December 2009	Adult	Female	#13	Suspected harvest
December 2009	Adult	Male	#12	Lost Canyon, Bears Paws
January 2010	Adult	Male		Camp Cr., BLM

Table 7. Survival rates of cougars collared in Bears Paws and Little Rockies, north-central Montana 2006-2010.

Survival Model	Survival/Mortality Rate	95% CI
2007 all survival	0.27	0.00 – 1.00
2008 all survival	0.62	0.32 – 1.00
2009 all survival	0.11	0.02 – 0.50
Male survival 2006-2010	0.01	0.00 – 0.29
Female survival 2006-2010	0.02	0.00 – 0.91
All survival 2006-2010	0.01	0.00 – 0.16
All harvest mortality 2006-2010	0.81	0.58 – 1.00
All natural mortality 2006-2010	0.18	0.00 – 0.41

A minimum of 11 cougars were harvested in the Little Rockies (Table 6). Four females and 1 male cougar were harvested on Ft. Belknap and 1 female and 2 males were harvested on public land in the Little Rockies during the fall and winter 2009/2010. Another adult female was killed near the reservation boundary in December 2009.

A hunter harvested #8 on the Ft. Belknap in December 2009. This young male dispersed from the Rocky Boys where he was collared the previous winter. We retrieved the collars from female #10 and #11. Cougar #10 died of natural causes.

6. Overall Summary

Harvest and Mortality

We collared 6 females and 8 males. Three males and 1 female were subadults. Of the 13 cougars for which we have data on ultimate fate, (including #3 probable harvest and censoring #4 whose fate is unknown), hunters harvested 9, 2 cougars died of natural causes, and 2 are still presumed alive. During the period of December 2006 (1st capture) through May 2010 the overall survival rate was 0.01 (Table 7). Hunter harvest mortality rate for that period was 0.81. Sample sizes for testing rate differences among years and between sexes were too small (Table 7). Mean number of months alive post capture for cougars was 8 (range = 1-12).

At the beginning of 2008/2009 hunting season we only knew of 1 adult male (# 2) and 1 subadult (# 8) on Rocky Boys. We did not capture or find any adult male cougar tracks after January 2009 and we caught a subadult male cougar (#12) in May 2009 (harvested 12/09).

At the beginning of 2009/2010 hunting season we only knew of 2 adult cougars in the Bears Paws, including #12. To our knowledge, cougar #12 was the only cougar harvested in the Bears Paws that winter (Table 6). We found tracks of 1 adult female with kittens in early January 2010. We captured the juveniles, but these kittens were too small to collar. We recaptured and collared the subadult male in early May.

We estimated 10-12 adult cougars in Little Rockies before the 2009/2010 hunting season. We released dogs on cougar tracks twice on Ft. Belknap during winter 2010 but did not capture any lions. We estimated that over 50% of the adult/subadult cougar population including over 66% of adult females in the population were killed that winter in the Little Rockies.

We assume that high immigration (or possibly there were more cougars in population than we detected) likely supported the high harvest of males in 2008/2009. We estimated 2 female cougars (1 of these has 2 kittens) and no male cougars on or adjacent to Rocky Boys and 3 females and 1-2 males in Little Rockies.

One of 12 radioed cougars (#8) dispersed. He dispersed from the Bears Paws to Ft. Belknap and was killed there.

Population Parameters

We searched 130 km^2 of the Bears Paws study area for 2 years and estimate the core habitat for cougars in the Bears Paws is about 260 km^2 yielding a density of 1.5 adult cougars/100 km^2 during periods on known high population and a density of 0.7/100 km^2

Table 8. Male and female combined mountain lion winter resource selection function (RSF) showing variable, beta coefficient, standard error, z score and Wald chi-square p-value. For categorical variables (see table 1) those not in the model are included in the constant term. For distance variables a positive coefficient shows avoidance (i.e. use increases with distance) while negative coefficients show selection (i.e. use decreases with distance). Squared variables are quadratic terms and reveal an intermediate level selection.

Covariate	Coefficient	Standard Error	Z	P>|Z|
South Aspect	0.3181	0.0274	11.6	0
High Montane	-1.3883	0.3093	-4.49	0
Agriculture	-1.9151	0.1512	-12.66	0
Developed	-0.6110	0.1706	-3.58	0
Transitional Vegetation	-0.7200	0.0453	-15.89	0
Elevation	0.0191	0.0002	72.32	0
Elevation2	-0.000006	8.67E-08	-77.5	0
Percent Slope	0.02648	0.0017	15.45	0
Percent Slope2	-0.00015	1.96E-05	-8.06	0
Distance from forest	-0.0078	0.0002	-33.71	0
_Constant	-14.9483	0.2250	-66.43	0

during periods on lowest known population. Density estimates for cougars in North America range from 0.32-2.2 resident adults/100 km^2 (Logan et al. 2000).

We collared 5 adult females and 2 of these had kittens. One of 2 adult females in Bears Paws had 3 kittens and one of 3 females in Little Rockies had 2 kittens. We did not determine the fates of these kittens.

Three female home ranges (MCP) ranged from 95-326 km^2 (Figure 1). Five male home ranges ranged from 160-472 km^2. The composite home range for 8 cougars was 931 km^2.

Resource Selection

We used 1,786 GPS locations from 4 males and 2 females in the Bears Paws for model training and 281 GPS location from 2 males in the Little Rockies and 785 locations from 2 males in CMR for model validation. Most cougar locations were within habitats we predicted and defined as cougar habitat based on ruggedness and forest cover model of Riley and Malecki (2001; Figure 1). Males and females combined selected for increasing elevation and slope and against distance from forest and open (logged, burned) forest (Table 7). Selection was relatively similar for males vs females. (Tables 9 and 10, Figure 4).

Based on moving window analysis, we estimated 375 km^2 of suitable habitat on Rocky Boys 674 km^2 on Fort Belknap and 4,539 km^2 in the remainder of the project area. Based on comparison to other areas of known population density, and given current prey abundance and habitat quality, that 5,588 km^2 could support approximately 116-156 cougars with an additional 32-43 in the remainder of northeastern Montana. Rocky Boys could support 11-14 and Ft. Belknap could support 9-12 cougars.

Conflicts

We found no evidence that any of our radioed cougars had conflicts with livestock or humans despite extensive overlap with allotments where cattle were present. We observed no evidence that bighorn sheep (including radio collar sheep reintroduced to the Bears Paws) were killed by cougars.

7. Discussion

Human harvest was the primary factor limiting cougars in the Bears Paws and Little Rockies during the study period. The harvest rates we report are higher than those reported from 2002-2006 (range = 0-2 cougars killed/year) but similar to levels from 1992-2001 (range = 3-8; MFWP unpublished data). Cougar population abundance and snow conditions allowing for harvest may be factors in this trend. Based on the high rate of mortality of cougars in the Bears Paws

Table 9. Female mountain lion winter resource selection function (RSF) showing variable, beta coefficient, standard error, z score and Wald chi-square p-value. For categorical variables (see table 1) those not in the model are included in the constant term. For distance variables a positive coefficient shows avoidance (i.e. use increases with distance) while negative coefficients show selection (i.e. use decreases with distance). Squared variables are quadratic terms and reveal an intermediate level selection.

Covariate	Coefficient	Standard Error	Z	P>|Z|
South Aspect	0.2850	0.0310	9.18	0
High Montane	-1.3055	0.3163	-4.13	0
Agriculture	-2.0156	0.1687	-11.94	0
Developed	-1.5771	0.2724	-5.79	0
Transitional Vegetation	-0.6593	0.0497	-13.26	0
Elevation	0.0217	0.0009	23.67	0
Elevation2	-0.000007	2.97E-07	-26	0
Percent Slope	0.0277	0.0020	13.8	0
Percent Slope2	-0.0001	2.29E-05	-8.26	0
Distance from forest	-0.0085	0.0002	-31.33	0
_Constant	-14.7684	0.6964	-21.21	0

Table 10. Male mountain lion winter resource selection function (RSF).

Covariate	Coefficient	Standard Error	Z	P>|Z|
South Aspect	0.4720	0.0604	7.81	0
Agriculture	-1.2969	0.3501	-3.7	0
Transitional Vegetation	-0.9816	0.1154	-8.5	0
Elevation	0.0193	0.0010	18.09	0
Elevation2	-0.000006	3.16E-07	-19.19	0
Percent Slope	0.0211	0.0038	5.55	0
Percent Slope2	-0.00005	4.29E-05	-1.26	0.208
Distance from forest	-0.0054	0.0004	-11.67	0
_Constant	-14.8581	0.8989	-16.53	0

and in the Little Rockies, we hypothesize that these ranges may be “attractive sinks” for cougars (Novoro et al. 2005, Kunkel et al. 2007, Robinson et al. 2008). The pre- harvest density of cougars in the Bears Paws was relatively high. Should harvest rates remain high, we hypothesize a reduction in mean male age and a reduction in overall regional cougar density (Stoner et al. 2006). We are uncertain where the local source population(s) of cougars are that provide immigrants into Bears Paws and Little Rockies, but hypothesize the Missouri River Breaks including the CM Russell National Wildlife Refuge (CMR) serve as one as cougar harvest is not allowed in CMR. The low number of kittens we have found recruited preliminarily indicates that the Bears Paws and Little Rockies are not self sustaining population but rather rely on immigration. The high turnover of males from harvest in fact may be the cause of low kitten survival and social instability may lead to poor breeding success (Ruth et al. 2011).

Stoner et al. (2006) reported cougar annual survival rates of 0.36 in Utah during 5 years of intensive harvest. They reported that cougar removal ranged from 17.6–54.5% of the adult population and exceeded 40% for 4 of 5 consecutive years. Under this regime the population declined by >60%. Following 3 subsequent seasons of light harvest the population recovered to 52.4% of its original level. Ruth et al. (2011) found that to generate an increasing population (lambda > 1.00) adult female survival needed to be >0.93.

The harvest rate in our project area was similar to a population of cougars in southern New Mexico subject to very high removal levels where management for bighorn sheep restoration was the goal (Kunkel et al. 2007). The number of cougars killed there every year was >50% of the minimum number of cougars estimated to have been present. The number of days that cougars remained alive (or in the study area) after being radio collared ranged from 14 to 1,047 (x = 303.3), very close to the time alive after collaring that we report here (8 months). High immigration supported that apparent attractive sink in New Mexico.

We found evidence of connectivity between the Bears Paws and Little Rockies and between the Little Rockies and Missouri River Breaks. Location data from 1 cougar indicates connectivity may occur via the area designated within the Upper Missouri River Breaks National Monument, which supports predictions of our habitat model (Figure 1) and is supported by our RSF (Figure 2). Our camera survey also indicated this connection and yielded a density of 0.48-0.73 cougars/100 km^2 in the UMRBNM (Kunkel 2006). More work is needed to determine if source populations and movement rates among these areas can sustain local and regional harvest.

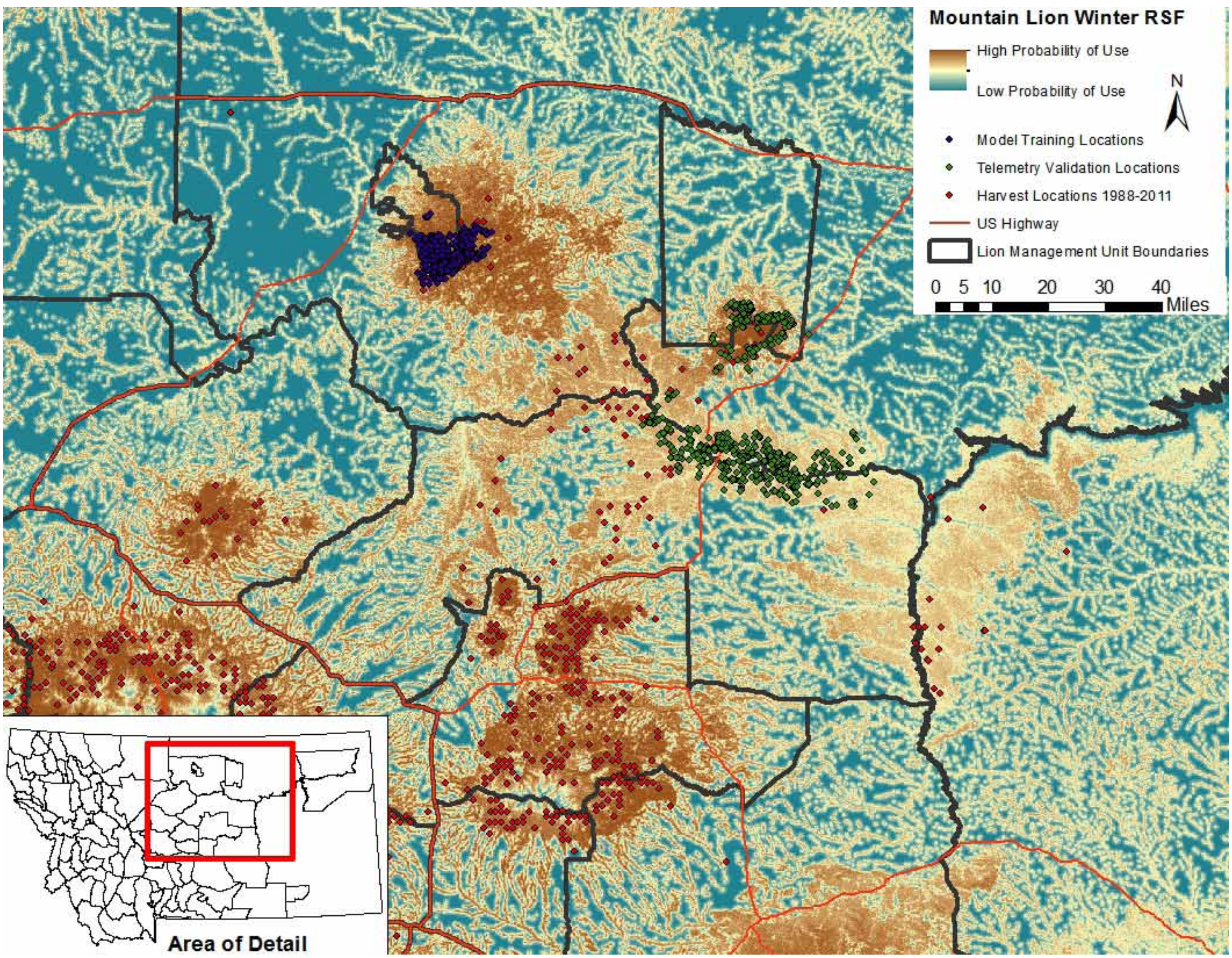


Figure 4. Mountain lion winter Resource Selection Function output.

8. Management Recommendations

We recommend a cooperative, regional, and conservative management approach similar to that recommended by Ruth et al. (2011) for the northern Yellowstone ecosystem. Those recommendations would include identifying size of source populations and meta-population structure, managing access, and keeping female harvest quotas low. We recommend harvest reductions to prevent high harvest of females like those occurring in winter 2009/2010. Ruth et al. (2011) also recommend minimizing road access in key winter ranges to reduce harvest.

Our RSF model indicates the region can support a greater number and distribution of cougars than currently exist, and we recommend harvest levels in the short term that allow more habitat to become occupied. This will allow greater harvest levels in the future and help create long term local population viability. Given that we found no significant conflicts between cougars and livestock or humans, we see opportunity for increased cougar abundance before social carrying capacity is reached. Of course, we also recommend education and public involvement for establishing these goals. Deer and elk populations in the region were over objective (MFWP unpublished data) and thus we see no conflict in this regard either. Further, the Cougar Management Guidelines Working Group (2005) found no scientific evidence to support role of hunting cougars in benefitting wild ungulate populations or in reducing livestock depredations. Nor does recent research support such (Hurley et al. 2011, Griffith et al. 2011).

We also recommend implementation and research of a program promoting livestock husbandry practices to reduce risk of depredations from large carnivores (Cougar Management Guidelines Working Group 2005, Woodroffe et al. 2007, Beier 2010). This will be important also as wolves recolonize the region.

Probably most importantly, we recommend stakeholders work together to define shared objectives for cougar management in the region. Cougars are the only large predator in the region currently and thus play an important ecosystem function (Ripple and Beschta 2006). The development of a cooperative (MFWP, USFWS, WWF, RBIR, FBIR, University of Montana) research project in CMR is a step in that direction.

9. Next Steps

We expanded this project to the CMR in 2010 with USFWS, University of Montana, and FWP. To date, 5 males and 1 female have been captured and fitted with GPS collar. Two additional females have been treed and 6 kittens were found. That work is ongoing and should yield better knowledge of regional cougar meta-population dynamics and source-sink structure of the landscape. From that we can assess population viability and develop collaborative regional conservation and management plans.

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11. Literature

Anderson, C. R., Jr. and F. G. Lindzey. 2003. Estimating cougar predation rates from GPS location clusters. Journal of Wildlife Management 67:307-316.

Atwood, T.C., E.M. Gese, and K.E. Kunkel. 2010. Spatial Partitioning of Predation Risk in a multiple predator- multiple prey system. Journal of Wildlife Management 73:876-884.

Atwood, T.C., E. M. Gese, and K. E. Kunkel. 2007. Comparative patterns of predation by cougars and recolonizing wolves in Montana's Madison range.

Journal of Wildlife Management 71:1098–1106.

Beier, P. 1995. Dispersal of juvenile cougars in fragmented habitat. Journal of Wildlife Management 59:228-237.

Beier P. 1996. Metapopulation models, tenacious tracking, and cougar conservation. Pages 293-323 in D.R. McCullough editor. Metapopulations and Wildlife Conservation, Island Press

Beier, P. 2010. Cougars and conservation planning. Pages 177–189 in M. Hornocker and S. Negri, editors. Cougar ecology and conservation. University of Chicago Press, Chicago, Illinois, USA.

Beyer, H. L. 2004. Hawth's Analysis Tools for ArcGIS. Available at http://www.spatialecology.com/htools.

Bolker, B. M., M. E. Brooks, C. J. Clark, S. W. Geange, J. R. Poulsen, M. H. H. Stevens, and J.-S. S. White. 2009. Generalized linear mixed models: a practical guide for ecology and evolution. Trends in Ecology & Evolution 24:127-135.

Boyce, M. S., P. R. Vernier, S. E. Nielsen, and F. K. A. Schmiegelow. 2002. Evaluating resource Selection functions. Ecological Modelling 157:281-300.

Boyd, D. K., and D. H. Pletscher. 1999. Characteristics of dispersal in a colonizing wolf population in the central Rocky Mountains. Journal of Wildlife Management 63:1094-1108.

Burnham, K. P., and D. R. Anderson. 1998. Model selection and inference: a practical information-theoretic Approach. Springer-Verlag, New York.

Carroll, C., M. K. Phillips, N. H. Schumaker, and D.W. Smith. 2002. Impacts of landscape change on wolf restoration success: Planning a reintroduction program using static and dynamic models. Conservation Biology 17:1-15.

Cougar Management Guidelines Working Group. 2005. Cougar Management Guidelines. Wild Futures, Bainbridge Island, Washington, USA.

Craighead, F. L., M. E. Gilpin, and E. R. Vyse. 1999. Genetic considerations for carnivore conservation in the Greater Yellowstone Ecosystem. Pages 285-321 in T. W. Clark, A. P. Curlee, S. C. Minta, and P. M. Kareiva, editors. Carnivores in ecosystems the Yellowstone experience. Yale University Press, New Haven, Connecticut, USA.

Dalerum, F., M. Somers, K. Kunkel, and E. Cameron. 2008. The potential for large carnivores to act as biodiversity surrogates in southern Africa. Biodiversity and Conservation 17:2939-2949.

Doak, D. F. 1995. Source-sink models and the problem of habitat degradation: general models and application to the Yellowstone grizzly. Conservation Biology 9:1370 -1379.

ESRI. 2008. ArcMap 9.3. URL: www.esri.com.

Estes, J.A. et al. 2011. Trophic downgrading of planet Earth. Science 333:301–306

Fielding, A. H., and J. F. Bell. 1997. A review of methods for the assessment of prediction errors in conservation presence/absence models. Environmental Conservation 24:38-49.

Forrest, S.C., H. Strand, W.H. Haskins, C. Freese, J. Proctor, and E. Dinerstein. 2004. Ocean of

Grass: A Conservation Assessment for the Northern Great Plains. World Wildlife Fund, Northern Great Plains Ecoregion, Bozeman, MT. http://worldwildlife.org/wildplaces/negp/pubs/ocean_of_grass.cfm

Gillies, C. S., M. Hebblewhite, S. E. Nielsen, M. A. Krawchuk, C. L. Aldridge, J. L. Frair, D. J. Saher, C. E. Stevens, and C. L. Jerde. 2006. Application of random effects to the study of resource selection By animals. Journal of Animal Ecology 75:887-898.

Griffin, K. A., M. Hebblewhite, H. S. Robinson, P. Zager, S. M. Barber-Meyer, D. Christianson, and P. J. White. 2011. Neonatal mortality of elk driven by climate, predator phenology and predator community composition. Journal of Animal Ecology, 80:1246-1257.

Haight, R. G., D. J. Mladenoff, and A. P. Wydeven. 1998. Modeling disjunct gray wolf populations in semi-wild landscapes. Conservation Biology 12:879-888.

Heisey, D. M. 1985. Micromort user's guide. NH Analytical Software, St. Paul, Minnesota, USA.

Heisey, D. M., and T. K. Fuller. 1985. Evaluation of survival and cause-specific mortality rates using telemetry data. Journal of Wildlife Management 49:668-674.

Hosmer, D. W., and S. Lemeshow. 2000. Applied logistic regression. 2nd edition. Wiley, New York.

Hurley, M. A., J. Unsworth, P. Zager, M. Hebblewhite, E. O. Garton, D. M. Montgomery, and C. L. Maycock. 2011. Demographic Response of Mule Deer to Experimental Reduction of Coyotes and Mountain Lions in Southeastern Idaho. Wildlife Monographs178:1-33.

Kunkel, K. E. 1997. Predation by wolves and other large carnivores in northwestern Montana and southeastern British Columbia. Ph. D. Dissertation, University of Montana, Missoula, Montana, USA.

Kunkel, K.E. 2003. Ecology, conservation, and restoration of large carnivores in western North America. Pages 250-295 in C.J. Zabel and R.G. Anthony editors. Mammal community dynamics in western coniferous forests of North America: management and conservation issues. Cambridge University Press, UK.

Kunkel, K. E. 2006. Testing the potential of camera traps for estimating cougar (Puma concolor) distribution and relative abundance in the Missouri River breaks of northcentral Montana. Unpublished Report to Northern Great Plains Program, World Wildlife Fund.

Kunkel, K. E. T. K. Ruth, D. H. Pletscher, and M. G. Hornocker. 1999. Winter prey selection by wolves and cougars in and near Glacier National Park, Montana. Journal of Wildlife Management 63:901-910.

Kunkel, K. E., Z. Parsons, R. Thompson, H. Quigley, M. Hornocker, D. Pletscher, P. Bangs, and M. Phillips. 2007. Conservation and predation ecology of cougars and desert bighorn sheep in New Mexico. Turner Endangered Species Fund Conservation Report 07-01.

Kunkel, K.E, T.C. Atwood, T.K. Ruth, D.H. Pletscher, and M.G. Hornocker. 2012. Assessing wolves and cougars as conservation surrogates. Accepted, Animal Conservation

Laundre, J. and T. W. Clark. 2003. Managing puma hunting in the western United States: through a metapopulation approach. Animal Conservation 6:159-170.

Licht, D. J., Millspaugh, K. E. Kunkel, C. Kochanney, R. O. Peterson. 2010. Using small populations of wolves for ecosystem restoration and stewardship. Bioscience Forum 60:147-153.

Logan, K. A. and L. L. Sweanor. 2000. Puma. Pages 347-377 in S. Demaris and P. R. Krausman editors. Ecology and management of large mammals in North America. Prentice Hall, Upper Saddle River, New Jersey, USA

Manly, B. F. J., L. L. McDonald, D. L. Thomas, T. L. McDonald, and W. P. Erickson. 2002. Resource selection by animals : statistical design and analysis for field studies. 2nd edition. Kluwer Academic Publishers, Dordrecht ; Boston.

Menard, S. W. 2002. Applied logistic regression analysis. 2nd edition. Sage Publications, Thousand Oaks, Calif.

Minta, S. C., P. M. Kareiva, and A. P. Curlee. 1999. Carnivore research and conservation: learning from history and theory. Pages 323-404 in T. Clark, A. P. Curlee, S. P. Minta, and P. M. Karieva, editors. Carnivores in ecosystems. Yale University Press, New Haven Connecticut, USA.

Mladenoff, D. J., T. A. Sickley, and A. P. Wydeven. 1999. Predicting gray wolf landscape recolonization: logistic regression models vs. new field data. Ecological Applications 9:37-44.

Montana Fish, Wildlife and Parks. 1996. Final environmental impact statement: Management of mountain lions in Montana. Montana Fish, Wildlife and Parks, Helena, Montana, USA

Novaro, A. J., K. H. Redford, and R. E. Bodmer. 2000. Effect of Hunting in Source-Sink Systems in the Neotropics Conservation Biology 14: 713–721.

Pyare, S. and J. Berger. 2003. Beyond demography and delisting: ecological recovery for Yellowstones's grizzlies and wolves. Biological Conservation 113-63-72.

Rabe-Hesketh, S., A. Skrondal, and A. Skrondal. 2008.

Multilevel and longitudinal modeling using stata. 2nd edition. Stata Press Publication, College Station, Tex.

Riley, S. J. and R. A. Malecki. 2001. A landscape analysis of cougar distribution and abundance in Montana, USA. Environmental Management 28:317-323.

Ripple, W. J., and R. L. Beschta. 2006. Linking a cougar decline, trophic cascade, and catastrophic regime shift in Zion National Park. Biological Conservation 133:397–408.

Ritchie, E. G., E. Bodil, S. Alistair A. Glen, M. Letnic, G. Ludwig, and R. A. McDonald. 2012. Ecosystem restoration with teeth: what role for predators? Trends in Ecology and Evolution 27:265-271.

Robinson, H. S., R. B. Wielgus, H. S. Cooley, and S. W. Cooley. 2008. Sink populations in carnivore management: cougar demography and immigration in a hunted population. Ecological Applications 18:1028–1037.

Ruth, T. K. M. A. Haroldson, K. M. Murphy, P. C. Buotte, M. Hornocker, and H. B. Quigley. 2011. Cougar Survival and Source-Sink Structure on Greater Yellowstone's Northern Range. Journal of Wildlife Management 75:1381-1398.

Smith, D. W., R. O. Peterson, and D. Houston. 2003. Yellowstone after wolves. Bioscience 53:330-340.

Soule, M. E., J. A. Estes, J. Berger, and C. Matinez Del Rio. 2003. Ecological effectiveness: conservation goals for interactive species. Conservation Biology 17:1238-1250.

Stephens, P. A., S. W. Buskirk, G. D. Hayward, and C. Martinez del Rio. 2005. Information theory and hypothesis testing: a call for pluralism. Journal of Applied Ecology 42:4-12.

Stoner, D. C., M. L. Wolfe, and D. M. Choate. 2006. Cougar exploitation levels in Utah: Implications for demographic structure, population recovery, and metapopulation dynamics. Journal of Wildlife Management 70:1588-1600.

Sweanor, L. L., K. A. Logan, and M. G. Hornocker. 2000. Cougar dispersal patterns, metapopulation dynamics, and conservation. Conservation Biology 14:798-808.

Terborgh, J., J. A. Estes, P. Paquet, K Ralls, D. Boyd-Heger, B. J. Miller, and R. F. Noss. 1999. The role of top carnivores in regulating terrestrial ecosystems. Pages 39-64 in M. E. Soule and J. Terborgh, editors. Continental conservation scientific foundations of regional reserve networks. Island Press, Washington, D. C., USA.

The Nature Conservancy 1999. Ecoregional planning in the Northern Great Plains Steppe.

Williams, J. S. 1992. Ecology of mountain lions in the Sun River area of northern Montana. M.S. thesis, Montana State University, Bozeman.

Woodroffe, R. and J. R. Ginsberg. 1998. Edge effects and the extinction of populations inside protected areas. Science 280:2126-2128.

Woodroffe, R., F. Laurence, G. Frank, P. A. Lindsey, S. M. K. ohe Ranah, and S. Romanach. 2007. Livestock husbandry as a tool for carnivore conservation in Africa's community rangelands: a case–control study. Biological Conservation 16:1245-1260