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July 1, 2014 – June 30, 2015

WILDLIFE RESEARCH REPORT

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ABSTRACT

Colorado Parks and Wildlife (CPW) conducted a 10-year (2004-2014) puma study on the Uncompahgre Plateau to quantify puma population dynamics in the absence (*reference* period, years 1-5) and presence (*treatment* period, years 6-10) of sport-hunting. The purpose of the study was to evaluate the assumptions underlying the CPW puma management program with sport-hunting in Colorado. The *reference* period began December 2004 and ended October 2009 and the *treatment* period began November 2009 and ended all data collection in December 2014. 109 pumas were captured and marked in the *reference* period and 115 pumas were captured and marked in the *treatment* period. Those animals produced known-fate data for 75 adults, 75 subadults, and 118 cubs. This report summarizes results of early preliminary stages of data analyses. In the absence of sport-hunting, the puma population increased and exhibited high survival rates and a high fecundity rate. There was a clear treatment effect with sport-hunting. The puma population declined substantially after 3 hunting seasons at a 15% design harvest of independent pumas. An 11-12% design harvest of independent pumas was applied in the final 2 years of the *treatment* period. The *treatment* period puma population also exhibited substantially lower survival rates of adults, subadults, and cubs, and a lower fecundity rate. Data analyses are ongoing and will ultimately inform future puma management in Colorado.

WILDLIFE RESEARCH REPORT

ASSESSING EFFECTS OF HUNTING ON A PUMA POPULATION ON THE UNCOMPAHGRE PLATEAU, COLORADO

Kenneth A. Logan

PROJECT NARRATIVE OBJECTIVES

1. Gather data on puma population abundance, sex and age structure, vital rates (i.e., reproduction, age-stage survival rates, and emigration and immigration rates if possible), and agent-specific mortality in a non-hunted puma population phase and a hunted puma population phase for use in modeling puma population dynamics and evaluating and structuring puma harvest management and research approaches.
2. Test current CPW puma harvest-related assumptions that are applied to puma populations in DAUs, and arrive at acceptable harvest levels intended to achieve population objectives, including increases, stability, and reductions in the puma population.
3. Apply a hunting treatment to the puma population on the Uncompahgre Plateau study area designed to test CPW harvest-related assumptions and learn about impacts of hunting on pumas.
4. Develop methods that detect changes in puma population abundance on the Uncompahgre Plateau study area that might be useful for monitoring changes in puma abundance in other puma habitats.

SEGMENT OBJECTIVES

1. Complete data collection of the fifth and final year of the five-year *treatment* period by working with CPW biologists and managers to manipulate the puma population with sport-hunting and to survey hunters.
2. Complete gathering data on puma population sex and age structure.
3. Complete gathering data for estimates of puma reproduction rates.
4. Complete gathering data to estimate puma sex and stage-specific survival rates.
5. Complete gathering data on agent-specific mortality.
6. Begin data analysis phase working with CPW Biometrician, Jon Runge.

Introduction

Colorado Parks and Wildlife (CPW) managers need reliable information on puma population biology to develop sound management strategies that address diverse public values and the CPW objective of actively managing pumas while "achieving healthy, self-sustaining populations" (Colorado Division of Wildlife 2002-2007 Strategic Plan:9). Active management of pumas includes managing for sustained populations to provide sport-hunting opportunity, and reducing puma populations to suppress depredation on livestock, predation on mule deer, and enhance public safety. Thus, sport-hunting is intended as a tool for puma management in addition to recreation. Because sport-hunting is a major cause of death for pumas in hunted populations (Murphy 1983, Logan et al. 1986, Anderson et al. 1992, Ross and Jalkotzy 1992, Lambert et al. 2006, Stoner et al. 2006, Laundré et al. 2007), managers need information to better understand how hunting impacts puma populations and methods to monitor changes in puma abundance to assess how management actions are working to meet management objectives.

To improve the biological basis for managing pumas, the CPW began a process in year 2000 to develop puma Data Analysis Unit (DAU) plans (Colorado Division of Wildlife 2007). The DAU plans involved a formulation or deductive model to project an expected number of pumas on available habitat and the level of sport-harvest deemed acceptable to achieve one of two management objectives for each DAU: 1) to maintain a stable or increasing puma population, or 2) to suppress the puma population. A series of "best judgments" and assumptions by CPW managers on puma populations in DAUs was necessary because reliable and affordable methods for estimating puma population abundance in habitat were not available, and there was no information on impacts of hunting on Colorado puma populations. Consequently, managers that developed DAU plans mostly used data from intensive puma population studies from other western states that were published in the literature and from information from studies of puma in Colorado (Anderson et al. 1992) as a guide. The information included estimates of puma population density, sex and age structure, population rates of increase, and expected impacts of harvest rates, and that information was extrapolated to expected puma habitat across Colorado.

Current CPW (CDOW 2007) management assumptions include: 1) Puma densities range from 2.0−4.6 pumas/100 km^2. 2) A moderate annual rate of growth of 15% (*i.e.,* $\lambda = 1.15$) for the adult and subadult puma population. 3) For DAUs managed for a stable or increasing puma population, acceptable total mortality could fall in the range of 8 to 15% of the projected huntable population (i.e., adult plus subadult pumas). 4) In addition, for DAUs with a management objective for a stable-to-increasing puma population, acceptable female (i.e., adults and subadults) mortality could fall in the range of 35 to 45% of the total mortality. 5) For DAUs managed to suppress the puma population, total mortality could fall in the range of >15 to 28% of the projected huntable population of adult plus subadult pumas.

Prior to the current puma research described in this report, none of these demographic prescriptions had been tested for their validity on a puma population in Colorado. Such testing is prudent because some biological judgments made for DAU management plans might be in error and cause unintended consequences to puma populations, such as cause puma populations to decline where the management objective is for stable or increasing puma populations- the critical component for providing resiliency in the puma population to effects of hunting mortality.

Metrics from research in other western states support or are at variance with current CPW puma harvest guidelines for a stable to increasing population. Recent research in Wyoming indicated that a puma population could sustain a harvest comprised of 10 to 15% adult females, and population decline occurred when about 25% of adult females comprised the harvest (Anderson and Lindzey 2005:187). A Utah study found that a puma population declined when harvest exceeded 30% of the adults and subadults and comprised 42% females for 3 years (Choate et al. 2006). Another study in southern Idaho and northern Utah suggested that a harvest that included 15 to 20% of resident females probably would not reduce a puma population (Laundré et al. 2007). More recently, researchers in Washington modeled puma population dynamics and indicated that a 14% harvest of adult pumas was expected to result in a stable population and age structure (Beausoleil et al. 2013). Thus considering any of this information, if adult females comprise the majority of the current acceptable level of female harvest (i.e., 35-45%) in a Colorado DAU, and there is substantial error in the population projection, the puma population could decline. This result is possible because actual puma population estimates are not available for any DAUs, in fact numbers used are at best educated guesses or biological judgments extrapolated over huge non-surveyed areas, and would be problematic if errors occurred for a substantial number of DAUs where the management objective is for a stable-to-increasing population. Thus, the state-wide strategic objective of managing for a healthy, self-sustaining puma population could be in jeopardy. This emphasizes the need to quantify impacts of puma harvest on population parameters to structure guidelines that will likely achieve population objectives. This current study serves as an empirical test of the more theoretical guidelines that could be derived from the literature (previously cited).

To gauge the impact of management prescriptions on puma populations, wildlife managers need reliable, affordable methods to apply to representative DAUs. Already the CPW gathers information useful for guiding puma management through mandatory puma harvest reports and records on other detected mortality (e.g., road-kill, depredation control). Those data include sex, age-stage, location, and cause of death. In 2007, new efforts to improve the quality of the data included aging harvested pumas by tooth cementum-annuli and assessing population structure of pumas in Colorado using population genetics (J. Apker, Carnivore Management Coordinator, M. Alldredge, Mammals Researcher, personal commun.). Yet, the CPW needs to link those data to puma population dynamics influenced by harvest.

To address information needs, the CPW began this research in 2004 on the Uncompahgre Plateau to better understand puma population dynamics and effects of sport-harvest. The study was designed in two 5-year periods: a *reference* period (years 1 to 5) and a *treatment* period (years 6 to 10). The *reference* period provided baseline estimates on puma population abundance, sex and age structure, reproduction, survival, agent-specific mortality, and dynamics in representative puma habitat in Colorado where sport-hunting was not a cause of mortality. The *treatment* period occurred on the same study area and included manipulation of the puma population through the use of sport-hunting to provide information on the impact of hunting on a puma population and to evaluate methods intended to detect changes in the puma population.

Study Area

The study area for the puma population research is on the Uncompahgre Plateau (in Mesa, Montrose, Ouray, and San Miguel Counties; Fig. 1). The study area includes about 2,253 km^2 (870 $mi.^2$) of the southern halves of Game Management Units (GMUs) 61 and 62, and about 155 km^2 (60 $mi.^2$) of the northern edge of GMU 70 (between state highway 145 and San Miguel River). The area is bounded by state highway 348 at Delta, 25 Mesa road and Forest Service road FS503 to Nucla, state highway 97 to state highway 141 to state highway 145 to Placerville, state highway 62 to Ridgeway, U.S. highway 550 to Montrose, and U.S. highway 50 to Delta. This area comprised a Game Management Unit (GMU), the basic spatial unit used to manage pumas by CPW, for the purpose of this study on effects of sport-hunting on a puma population. The study area size represented the very largest GMUs for puma management in Colorado, therefore inferences from the study could be interpreted at the GMU population level.

The study area was typical of puma habitat in Colorado that has vegetation cover varying from pinion-juniper covered foothills starting from about 1,700 m elevation to the spruce-fir and aspen forests growing to the highest elevations of about 3,000 m. Mule deer (*Odocoileus hemionus*) and elk (*Cervus elaphus*) were the most abundant wild ungulates available for puma prey. Cattle and domestic sheep were raised on summer ranges on the study area. People reside year-round along the eastern and western fringe of the area, and there is a growing residential presence especially on the southern end of the plateau. A highly developed road system makes the study area easily accessible for puma research efforts. A detailed description of the Uncompahgre Plateau is in Pojar and Bowden (2004).

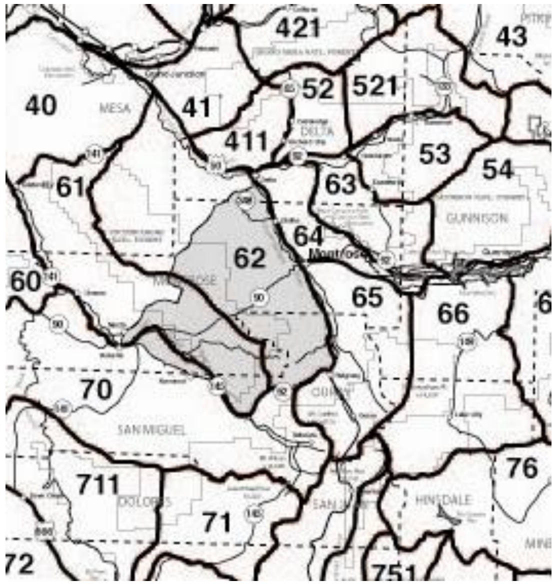

Figure 1. The puma study area on the southern half of the Uncompahgre Plateau, Colorado (shaded in gray) comprising the southern portions of Game Management Units (GMUs) 61 and 62 and a northern portion of GMU 70.

Expected Results

Results of this study inform CPW biologists and managers about expected puma population dynamics and biological impacts of sport-hunting and other causes of mortality (e.g., intra-specific strife, disease, poaching, vehicle collisions, depredation control) on a puma population in Colorado. The study reveal puma life history traits and management effects useful for developing sound management strategies. Moreover, this study evaluated the current puma management structure and assumptions used in puma harvest management through the examination of data gathered directly from a population-level manipulation. This study also assessed one method to detect changes in puma populations on a local intensive scale and for potential application on large representative management areas in collaboration with Mammals Researcher Dr. Mat Alldredge and colleagues. This information should assist the CPW to improve puma management in Colorado.

Approach

The puma population on the Uncompahgre Plateau study area was studied during a 5-year *reference* period (i.e., *reference* period years RY1-RY5) and manipulated during a 5-year *treatment* period (i.e., *treatment* period years TY1-TY5). The *reference* period provided baseline data on puma population dynamics (i.e., abundance, sex and age structure, survival, reproduction, agent-specific mortality, immigration and emigration) without puma sport-hunting as a cause of mortality. The study area was closed to puma hunting from November 2004 to October 2009. In addition, any radio-collared or ear-tagged pumas in the two Game Management Units (GMUs 61 north, 62 north) adjacent to the study area to the north were also protected from sport-hunting. This was an unreplicated case study on one geographic area having a before and after treatment effect design. This effort represented the most pumas ever studied in a population in Colorado and an unprecedented opportunity for CPW to learn about puma population dynamics and effects of sport-hunting.

Field Methods

Puma Population Status

Puma capture, marking, and sampling: The capture, marking, and GPS- or VHF- collaring of individual pumas and subsequent monitoring was essential to a number of project objectives, including obtaining: population counts, sex and age structure, estimates of vital rates, estimating detection probabilities per individual in camera grids, and movement data to evaluate emigration, vulnerability to hunters, and GMU and DAU boundaries.

Pumas were captured year-round using 3 methods: trained dogs, cage traps, and by hand (for small cubs). All captured pumas were examined to ascertain sex and describe physical condition and diagnostic markings. Ages of adult puma were estimated initially by the gum-line recession method (Laundre et al. 2000) and dental characteristics of known-age puma (Logan and Sweanor, unpubl. data). Ages of subadult and cub puma were estimated initially based on dental and physical characteristics of known-age puma (Logan and Sweanor unpubl. data). Ages of nurslings were estimated from apparent birthing dates indicated by GPS- and VHF-location data of collared mothers. Metric scale body measurements were recorded for each puma included: mass (kg), pinna length, hind foot length, plantar pad dimensions, total length and tail length. Tissue collections of adult and subadult pumas included: skin biopsy (from the pinna receiving the 6 mm biopsy punch for the ear-tags) and blood (30 ml from the saphenous or cephalic veins) and hair for genotyping individuals, parentage and relatedness analyses, and disease screening. Only skin and hair samples were collected from cubs ≤ 10 weeks old. Universal Transverse Mercator Grid Coordinates on each captured puma were fixed via Global Positioning System (GPS, North American Datum 27). All pumas were handled in accordance with approved Animal Care and Use Committee (ACUC) capture and handling protocols in ACUC file #08-2004 (Appendix I) and ACUC protocol #03-2007 titled, *Mountain Lion Capture and Handling Guidelines*.

Captured and handled adult, subadult, and cub pumas were marked 3 ways: GPS/VHF- or VHF-collar, ear-tag, and tattoo. The identification number tattooed in the pinna was permanent and could not be lost unless the pinna was severed. A colored (bright yellow or orange), numbered rectangular (5 cm x 1.5 cm) ear-tag (Allflex USA, Inc., DFW Airport, TX) was inserted into at least one pinna to facilitate individual identification during direct recaptures and when pumas were harvested.

Pumas captured by dogs usually climbed trees to take refuge. Adult and subadult pumas captured for the first time or requiring a change in telemetry collar were immobilized with Telazol (tiletamine hydrochloride/zolazepam hydrochloride) dosed at 5 mg/kg estimated body mass. The drug was delivered into the caudal thigh or shoulder muscles via a Pneu-Dart® shot from a CO_2-powered pistol (Pneu-Dart X-Caliber, Pneu-Dart Inc., Williamsburg, PA). A 3m-by-3m square nylon net was deployed beneath the puma to catch it in case it fell. A researcher climbed the tree, fixed a rope to two legs of the puma and lowered the cat to the ground with an attached climbing rope. Once on the ground, the puma's head was covered, its legs tethered, and vital signs monitored. (Normal signs: pulse ~70—80 bpm, respiration ~20 bpm, capillary refill time ≤2 sec., rectal temperature ~101°F average, range = 95—104°F) (Kreeger 1996). Treed pumas that could not be safely immobilized and handled were shot with a biopsy dart (8 mm long x 3 mm dia., Pneu-Dart Inc., Williamsburg, PA) fired from a CO_2-powered pistol to obtain a skin sample from the caudal thigh or shoulder. This sample was used in a study of puma population genetics.

Cage traps were used to capture adults, subadults, and large cubs. Pumas were lured into the trap using road-killed or puma-killed ungulates (Bauer et al. 2005, Sweanor et al. 2008). A cage trap was set only if a target puma (i.e., an unmarked puma, or a puma requiring a collar change) scavenged on the lure. Researchers continuously monitored the set cage trap from about 0.5 to 1 km distance by using VHF beacons on the cage and door. This allowed researchers to respond to the captured puma within 30 minutes. Pumas were immobilized with Telazol injected into the caudal thigh or shoulder muscles with a pole or hand syringe. Immobilized pumas were restrained and monitored as described above.

Small cubs (≤10 weeks old) were captured using our hands (covered with clean gloves) or with a catch pole. Cubs were restrained inside new burlap bags during the handling process and were not administered drugs. Cubs at nurseries were approached when mothers were away from nurseries as determined by radio-telemetry. Cubs captured at nurseries were removed from the nursery a distance of ~20-100 m to minimize disturbance and human scent at nurseries. Cubs were returned to the exact nurseries immediately after sampling processes were completed (Logan and Sweanor 2001).

Adult and subadult pumas were fitted with GPS collars (approximately 400 g each) or VHF collars (approximately 300 g each (Lotek Wireless, Newmarket, Ontario, Canada). Budget constraints limited the number of GPS collars (~10-15) available annually. Therefore, GPS collars were fitted to primarily adult pumas. GPS collars were programmed to fix and store puma locations at 4 times per day to sample daytime, nighttime, and crepuscular locations (i.e., 0:00, 06:00, 12:00, 19:00). This schedule seems optimal for sampling different parts of the day and to extend battery life (~18 months). Other adult and subadult pumas were fitted with VHF collars. Our efforts were to locate all collared pumas once per week from fixed wing aircraft and as weather and scheduling conditions allowed, for data on survival, agent-specific mortality, and location. We checked the live signal/mortality signal status from collared pumas from the ground opportunistically when we operated within their home ranges. VHF and GPS collars had mortality modes set to alert researchers when puma were immobile for 3 hours (VHF collars) to 24 hours (GPS collars) so that dead pumas could be found for data on survival and agent-specific mortality. Because subadult male pumas were not fully grown, they also received leather expansion links in their collars. The expansion links added 10-12 cm when open to allow the collars to be worn safely into the adult stage.

We attempted to collar all cubs in each observed litter with a small VHF transmitter mounted on an expandable collar (62 g, model 080, Telonics Inc., Mesa, AZ) when cubs weighed 1.3—10 kg. The collars were designed to operate for 10−12 months, and expanded to 54 cm circumference to accommodate growth. Cubs with mass ≥7 kg were fitted with a larger expandable collar (90 g, model 210, Telonics Inc., Mesa, AZ). The collars were designed to operate for 12−18 months and could expand to 54 cm circumference to accommodate growth. Cubs approaching the age of independence (~11−14 mo. old) were fitted with Lotek LMRT-3 VHF collars (~400 g) with leather expansion links that add 10−14 cm to the collar circumference to accommodate the adult puma neck size. These collars operated for 2−3 years. Cubs were recaptured when possible to replace collars as necessary. Monitoring collared cubs allowed quantification of survival rates and agent-specific mortality rates. Radio-collared offspring also provided information on movements, age of independence, recruitment, and emigration.

Puma population sampling considerations: The puma is one of the most difficult large mammals to study in North America because of its relatively low abundance on the landscape and its highly cryptic behavior. These characteristics were expected to influence the ability to sample individuals in the study population. The most efficient technique for locating and capturing pumas is detecting their tracks in snow and using trained dogs to pursue and secure them for sampling purposes. Hunters use the same technique to harvest pumas, which creates potential for biased survival rate estimates if researchers and hunters use similar strategies to detect and capture pumas. That is, with similar sampling strategies, pumas that are most vulnerable to being captured and radio-collared might also be more vulnerable to harvest, resulting in survival rates that are biased low. Hunters' detection of puma tracks is heavily influenced by road access. To minimize bias potential, we attempted to intensively search the entire study area for puma tracks, irrespective of road characteristics, thereby equally detecting puma with both higher and lower hunter-detection probabilities. Thus, our approach was to apply roughly equal (i.e., intensive, uniform) searching intensity across the study area and apply an alternative capture technique with bait and cage traps that did not rely on track detection to capture pumas, and attempt to directly monitor via VHF telemetry a large proportion of the population in the study area in order to reduce heterogeneity in sampling individuals.

Capture efforts to sample the adult and subadult pumas (i.e., independent pumas) subject to sport-hunting mortality in the study area population was conducted mainly during winter when snow cover maximized the detection and capture probability of pumas. Snow provided a continuous or almost continuous substrate that registered tracks of terrestrial mammals. Puma tracks were highly distinctive and at ground level could be accurately and consistently visually identified and distinguished from tracks of all other mammals by trained personnel in a variety of snow and weather conditions and in the variety of terrains and vegetation communities. This characteristic was the reason why most intensive puma population studies in the West have been conducted during winter- to maximize detection, quantification, classification and monitoring of animals in the populations (Hornocker 1970, Logan et al. 1986, Lindzey et al. 1992, Ross and Jalkotzy 1992, Spreadbury 1996, Anderson and Lindzey 2005, Lambert et al. 2006, Laundre et al. 2007, Cooley et al. 2008). Puma population research in winter also more directly linked the puma population investigated with animals killed during the hunting season, which in Colorado occurred annually during mid-November through March to facilitate the detection of pumas by hunters which mainly use trained dogs to capture the pumas. Snow also maximized the ability of trained dogs to follow scent in tracks and capture the pumas. In addition, during spring and fall and opportunistically in winter, we attempted to capture pumas in cage traps where pumas were attracted to road-killed deer baits, and puma prey kills. Individuals caught in cage traps were available to move about the study area during winter and be exposed to hunters.

The Uncompahgre Plateau study area was highly roaded, and from those roads branched ATV trails that further facilitated thorough searches of the study area to detect pumas. Still, the road system was not uniform, with some areas densely roaded, others moderately roaded, and one area in particular that did not allow motorized vehicles. The area is the combined Camelback Wilderness Study Area (BLM portion) and Roubideau Special Management Area (U.S. Forest Service portion) in the main fork of Roubideau Canyon. That non-roaded area was about 109 km^2 (42 $mi.^2$). Yet a system of roads and trails we used surrounded this area. We routinely handled this area by hiking up the lower reaches of Roubideau Canyon and onto upper benches and canyons to search for puma tracks. A puma capture team, involving 4 people on separate search routes, was detailed to search this region on the surrounding roads, ATV/snowmobile trails, and hiking paths. By visiting this area repeatedly each winter we expected to detect some pumas that used the canyon and that might not have been detected in the canyon in other search days. Pumas were expected to move out of the non-roaded portion of the canyon periodically during the winter and be exposed by their movements. Thus, periodic searches of any of the search routes was expected to increase exposure of the pumas to detection.

The study area was partitioned into search areas that a capture team could search within 1-2 days to detect puma tracks on snow within each area (Table 1). The intent was to structure a thorough, relatively uniform, systematic search effort across the study area and to repeat it multiple times during winter and spring. To cover the areas efficiently, we used four-wheel-drive trucks, all-terrain vehicles, snow-mobiles, and walking. When puma tracks ≤1 day old were detected, trained dogs were released to pursue the puma to capture, sample, and mark it. When puma tracks 1-2 days old were detected, we searched in the direction of travel of the puma in an effort to find ≤ 1 day old tracks that would facilitate pursuit of the puma. This sometimes lengthened our search within any particular area by another 1-2 days. When a GPS/VHF-collared puma was detected with radiotelemetry within 1 km (usually < 0.5 km) of the tracks and the direction of the tracks indicate that the puma was likely the collared individual, then we directed our efforts away from those tracks to focus our efforts on non-collared (i.e., non-sampled) pumas in the population to use our time more efficiently.

Table 1. Puma search areas on the Uncompahgre Plateau Study area.

West Slope	East Slope
25 Mesa Road to Cottonwood Creek and San Miguel Canyon (west reach)	25 Mile Mesa Road to east rim of Roubideau Canyon and Ben Lowe Mesa
Cottonwood Creek to Horsefly Canyon	Roubideau Canyon to Transfer Road
San Miguel Canyon (mid reach) to Maverick Draw	Transfer Road to east rim of Dry Creek Basin
Horsefly Canyon and San Miguel Canyon (mid reach) to Clay Creek	East rim of Dry Creek Basin to east rim of Spring Canyon
Clay Creek and San Miguel Canyon (upper reach) to McKenzie Creek	Spring Canyon to Happy Canyon
McKenzie Creek and San Miguel Canyon (upper reach) to Leopard Creek	Happy Canyon to Horsefly Canyon
	Horsefly Canyon to McKenzie Butte
	McKenzie Butte to Loghill Mesa

Reliability of population count methods: The approach described previously was expected to enable us to monitor a large proportion of the independent puma population on the study area in winter for reliable counts. On this point, we wanted direct evidence on the reliability of our field methods to study the puma population and make our winter counts. An opportunity for a one-time independent evaluation on the proportion of independent pumas on the study area that we might have marked was provided by an independent camera grid study conducted on our study area by Master of Science graduate student Kirsti Yeager (Colorado State Univ., Dep. of Fish, Wildlife, and Conservation Biology) and advisors Dr. William Kendall (Colorado Cooperative Fish and Wildlife Research Unit, Colorado State University) and Dr. Mat Alldredge (Mammals Researcher, CPW). This collaboration was part of a larger CPW supported project on the Colorado Front Range that evaluated the use of a grid with cameras, predator call boxes and DNA collection methods as a noninvasive method to collect puma tissue for capture-recapture models for estimates of puma abundance (Yeager et al. 2013).

A grid of 2 km x 2 km (4 sq. km) cells covering 540 km^2 was established on the east slope of the Uncompahgre Plateau study area. Eighteen cells were identified randomly for each of 3 survey periods each lasting about 28 days. Therefore, a total of 54 random cells were surveyed during December 2012 to March 2013. This period was in *treatment* year 4 (TY4). Within each random cell K. Yeager subjectively chose the "best" site to attract pumas by using vocal baits each consisting of a Fur-Finder ® (Magna, UT) electronic predator call of a distressed deer fawn. Each site also had a Reconyx ® PC900 Hyperfire camera (Holmen, WI) to record animal activity and hair-sampling devices (i.e., barbed-wire strands, sticky rollers) to attempt to acquire hair. This effort evaluated these methods for a non-invasive survey of puma abundance by using tissue to genetically identify individuals in a capture-recapture structure (Yeager et al. *in development*). This also allowed us to evaluate our field methods and proportion of independent pumas that were marked in the population.

Population Manipulation: The puma population on the Uncompahgre Plateau Study Area was manipulated by sport hunting after the 5-year *reference* period with no hunting. The hunting season was from mid-November and extended to January 31, unless the last puma on the design quota was killed before January 31, which effectively closed the season on the study area. The initial harvest quota was 8 pumas which represented a 15% harvest of the expected number of independent pumas in *treatment* year 1 (TY1). The predicted effect was that the 15% harvest of independent pumas would result in a stable or increasing population, an expectation that mangers used to guide puma harvest rates in Colorado. The quota of 8 was based on the projected number of 52 independent pumas expected on the study area in winter 2009-10 (TY1), modeled from count data in winter 2007-08 (RY4) (see Appendix II, Table AI.3). After it was evident that the number of independent pumas had declined during TY1 to TY3, we adjusted the harvest quota down to 5 pumas to represent an 11% harvest of the projected 45 independent pumas expected in TY4 in an effort to find a sustainable harvest rate useful to managers. The harvest quota of 5 was continued in TY5.

The number of hunters on the study area each winter was not limited. Each hunter on the study area was required to obtain a hunting permit from the CPW Montrose Service Center. Permits were free and unlimited. Each permit allowed the individual hunter with a legal puma hunting license in Colorado to hunt in the puma study area for 14 days from the issue date. Unsuccessful hunters that wanted to continue hunting past the permit expiration date could get a new permit for another 14 days or until the hunting season on the study area closed due to the quota being reached or the end of the hunting season. This permit system enabled CPW to estimate the number of hunters that actually hunted on the study area each season. In addition, a voluntary survey questionnaire (see Appendix III) was attached to each puma hunting permit issued to each hunter with a stamped envelope addressed to the CPW principal investigator. Hunters were asked to complete the survey as soon as possible for each hunting period associated with the permit in an effort to have hunters report the information while it was still fresh in their minds.

All pumas harvested on the study area were visually examined and sealed by the principal investigator as mandated by CPW. Hunters reported their puma kill to CPW within 48 hours of harvest and presented the puma carcass for inspection within 5 days of harvest. At the time of carcass check-in a mandatory CPW harvest check form was completed. In addition, an upper premolar tooth (i.e., PM^2) was extracted for aging by the cementum annuli method and a tissue sample was collected. Each successful hunter was asked to fill-out the one-page hunter survey form. All other hunters that did not report a puma kill on the study area were contacted by phone or in person and asked to complete the survey form as well. Many hunters returned the surveys on their own volition.

Mandatory hunter harvest checks provided accurate data on pumas removed from the study population for estimates of survival and agent-specific mortality. Hunters also provided data to evaluate the relative vulnerability of pumas to harvest and potential for hunter selectivity. Hunter harvest and capture events also revealed availability and sex and age classes of unmarked pumas on the study area during the hunting season and before our capture teams operated after the season to quantify the population.

After the design quota was filled and the study area closed to hunting, two puma research teams activated for capture operations with trained dogs and cage traps. One team operated on the east slope and one operated on the west slope of the study area to systematically and thoroughly search the study area to capture, sample, and GPS/VHF radiocollar pumas the remainder of winter and early spring.

Population Monitoring:

This monitoring plan enabled us to estimate the winter puma population abundance and sex and age structure each hunting season. Researchers monitored other population parameters, including: reproduction, survival and agent-specific mortality year-round. Movements of VHF- and GPS-collared pumas were also monitored. GPS- and VHF-collared pumas were fixed about once per week from light fixed-wing aircraft (e.g., Cessna 185) fitted with radio signal receiving equipment (Logan and Sweanor 2001). This monitoring enabled researchers to find GPS-collared pumas to acquire remote GPS location reports, monitor the status (i.e., live or dead) of individual pumas, and to locate carcasses for necropsy. Status of GPS- and VHF-collared pumas were monitored from the ground opportunistically using hand-held yagi antenna. GPS-collared pumas were monitored for survival status daily by using GPS-data that attempt location fixes 4 times daily (00:00, 06:00, 12:00, and 19:00). Cessation of activity (i.e., due to death) around those times allow a more accurate identification of time of death. Puma births occurred from March through September, but potentially they could happen any month of the year (Anderson et al.

1992, Laundre and Hernandez 2007, Logan 2008). Researchers estimated reproduction data on birth interval, litter size, sex ratio, survival, agent-specific mortality, and recruitment to later life stages (i.e., subadult, adult). Emigration was revealed with a sample of radio-collared or ear-tagged marked offspring that left the study area.

Analytical methods:

The population of interest to managers was the independent pumas (i.e., adults and subadults) in winter, which coincided with the puma hunting season in Colorado when snow cover maximized the vulnerability of pumas to hunting. As indicated previously, our winter research was designed to be thorough to search the study area to maximize the number of marked pumas while trying to reduce heterogeneity in sampling for population parameter estimation. This along with harvest statistics we attempted to obtain a complete count with attendant sex and age structure of the population that represented the Colorado hunting season from November through March. The counts consisted of the sum total of all known marked (i.e., radio-collared and ear-tagged) pumas on the study area, and non-marked harvested pumas plus any other pumas detected on the study area whose movements did not match movements of collared pumas and exhibited diagnostic characteristics of unique individuals (e.g., tracks distinguishing sex from hind-foot plantar pad measurements, counts of cub tracks with female tracks). In addition, we wanted to maximize the number of radio-collared pumas in all sex and age classes and to obtain a uniform distribution of those animals across the study area to represent animals in the population exposed to all causes of mortality.

Puma Population Trends

Puma population change was quantified by winter population counts. Data on agent-specific mortality, survival and reproduction rates were used to evaluate changes in population associated with the *reference* and *treatment* periods.

Puma Survival and Mortality Analysis

Adult puma survival and mortality was examined from data on radio-collared pumas that provided known-fate data (i.e., monitoring dates, estimated dates of death, cause of death). We used program MARK (White and Burnham 1999) (accessed January 12, 2015), the known fates data type and the logit link function to model survival rates with a candidate set of models structured to investigate factors that might explain variation in survival. MARK estimated survival rates, standard errors, and 95% confidence intervals for each model. Our main interest was the effect of the hunting treatment as partitioned among the *reference* and *treatment* periods on survival, because our research focus was to examine effects of sport-hunting on a puma population. Radio-location records for each adult puma were converted to monthly encounter histories. MARK estimated monthly survival rates using the modified Kaplan and Meier (1958) estimator that allowed staggered entry based on when we collared individuals and censoring of individuals if we lost contact with them (Pollock et al. 1989). We used data from year 2 of the *reference* (RY2) period to year 5 of the *treatment* period (TY5) (i.e., a 9 year span). We did not use data from *reference* year 1 (RY1) because we had just started the study and had collared only 7 adult pumas (3 males and 5 females). Encounter histories of individual adult pumas started on the day of capture, because no pumas died as a result of capture, or the beginning of RY2 (November 1, 2005). We censored individuals in the data if we did not receive its signal after the month of its last location. Individuals re-entered the data set if we recaptured them and fit them with a new collar. Death dates for puma were assigned to pumas with GPS collars based on the first day that GPS locations indicated that the pumas were immobile. Death dates for VHF-collared pumas were estimated based on previous live signal data and the mid-point of the span of days the puma was estimated to have died based on carcass decomposition. Causes of death were categorized to known human causes (e.g., harvest, depredation control, vehicle strike, poached), to known natural causes (e.g., intraspecific strife, injury), or to unknown natural causes.

Subadults puma survival and mortality was estimated for all known radio-collared and ear-tagged and tattooed pumas with known fates that spanned a 12-month subadult stage from 13 months up to 24 months of age. We did not know with certainty when all of the pumas in this 12-month age stage became independent, therefore some of the pumas may have been dependent for a period of time. Encounter histories for the pumas started as marked pumas entered the age stage. Histories started on the first day of capture for subadults caught and marked for the first time, because no subadults died as a result of capture. All histories were converted to monthly encounter histories. Death dates were assigned to harvest, depredation control, and observed vehicle strike dates. For other VHF-collared pumas where dates were not observed, dates were estimated as the mid-point of the span of days the puma was estimated to have died based on previous live signal data and carcass decomposition. The encounter histories were treated as known-fate data and entered into program MARK to model subadult puma survival rates using a candidate set of models that might explain the variation in survival rates.

Examining survival rates of adults and subadults, the legal harvest-age pumas, in the *reference* and *treatment* periods with contrasting models with and without the hunting treatment allowed us to assess changes in survival associated with the treatment effect. A treatment effect supported an inference that sport-hunting mortality was an important factor explaining the variation in puma survival and a factor that was largely additive if survival declined in association with the treatment. However, if models lacking the treatment effect received the most support, this would indicate that hunting mortality was primarily compensatory or that statistical power was insufficient to detect a treatment effect. If population growth of independent pumas also declined in association with treatment effect on survival, this change would further support that hunting-caused mortality was mostly an additive factor.

Cub survival and mortality was estimated for all radio-collared pumas 1 month to 12 months of age representing a stage when the pumas were dependent on their mothers. The large majority of the cubs in this data set were initially radio-collared as nurslings 1-2 months old. But we also included cubs collared at older ages, because we entered data so MARK would estimate monthly survival rates. In this way, use of data on the older cubs only added to the sample of older cubs and did not bias estimates because older cubs have a tendency to exhibit higher survival (Logan and Sweanor 2001, Ruth et al. 2011). Encounter histories for the cubs started on the first day they were collared. Three nursling cubs that died as a result of malfunctions of the design of the expandable radiocollars early in the study in the *reference* period were removed from the analysis. After the collars were modified, no other cub mortalities from the collars occurred. Causes of cub deaths were assigned after dead cubs were examined directly. Dates of death were estimated as the mid-point of the span of days the puma was estimated to have died based on dates of previous live signal data and carcass decomposition.

The assumption that each radio-collared cub was an independent random sample (i.e., distribution of mortalities among litters is random) may be violated because multiple cubs were often collared in litters and the fates of cubs within litters may be linked. For example, sometimes more than 1 or all cubs in a litter may die from the same proximate cause (e.g., infanticide by a male puma) or the survival of surviving cubs in a litter may be linked to death of siblings (e.g., resulting from greater individual maternal care). Violation of the independence assumption can result in unbiased survival point estimates, however, sample variances are expected to be underestimated, (i.e., overdispersion, Bishop et al. 2008). Therefore, we will examine validity of the independence assumption in data by estimating an over dispersion parameter, *c*-hat (Cooch and White 2015).

Model selection and parameter estimates

The candidate models were considered in importance in an information-theoretic approach (Burnham and Anderson 1998) using Akaike's Information Criterion adjusted for small sample sizes (AIC_c) to rank the models. We considered the models with the most support as those with the lowest AIC_c scores, high AIC_c weights (w_i), and models with $\Delta AIC_c \leq 2$ as having similar support (Burnham and

Anderson 2002). Survival estimates reported here were estimates in the top model and other supported models. Average monthly survival rates for adults were converted to annual survival rates (i.e., $S_{averagemonthly}^{12}$), standard errors, and 95% confidence intervals. Stage survival parameters for subadults and cubs were derived estimates calculated in MARK from monthly survival rates that produced average stage (i.e., 12-month) survival rates, standard errors, and 95% confidence intervals.

Reproduction

Female pumas with GPS/VHF collars were monitored the year round. Data from those pumas provided information on fecundity (i.e., proportion of adult females giving birth each year), litter size, secondary sex ratio (i.e., sex ratio of cubs born), birth intervals, and age at first breeding. Reproduction was verified by direct observations of cubs in nurseries and in direct association of adult females during capture efforts. Fecundity, defined as the proportion of adult female pumas giving birth each year, was estimated annually from reference year 2 (RY2) to through treatment year 5 (TY5) when we had ≥12 adult females in annual samples (there were only 4 adult females in RY1). Data on each adult female each year was coded with the individual identification number and as producing a litter of cubs (1) or not producing a litter (0) and whether the individual female produced a litter each year in the *reference* period (1) or the *treatment* period (2). Because adult females comprising the samples within each year were not independent of other years (i.e., some of the same females were monitored in a series of years within and among periods) mean period fecundity rates were modeled by using the generalized linear mixed model procedure (PROC GLIMMIX) in SAS (Version 9.3, 2010, SAS Institute) where the period was the fixed effect and individual puma identification was the random effect. We used the binomial distribution and logit link. We also investigated all adult females that exhibited extremely constrained GPS and VHF location clusters or movements that might indicate the birth of a litter for data on numbers and gender of cubs. When the cubs were 25 to 45 days old we entered the nurseries when the mothers were absent to examine the cubs and to mark them (previously described). We coded the data with each adult female identification number, the period in which the litter was produced (*reference*=1, *treatment*=2) and the number of cubs observed in each litter (1, 2, 3, 4). Similarly, because adult females comprising the samples within each year were not independent of other years and some occurred in both periods, we modeled period mean litter size using the mixed linear model procedure (PROC MIXED) in SAS, where period was the fixed effect and individual puma identification was the random effect. The sex ratio of cubs produced in the *reference* and *treatment* periods was compared to an expected 1:1 sex ratio by using the Goodness of fit Chi-square procedure in Zar (1984).

PRELIMINARY FINDINGS

Puma Capture

From December 2, 2004 to October 30, 2014 we captured ~256 individual pumas a total of 440 times on the Uncompahgre Plateau study area. None of the adult or subadult pumas died from capture procedures. However, 3 cubs died as a result of premature expansions of the radiocollars (indicated previously in Field Methods) and 1 cub was killed by our tracking dogs. We individually marked 226 pumas: 109 in the *reference* period and 115 in the *treatment* period. The number of radio-collared pumas monitored each year ranged from 16 to 56 and averaged 40. Marked pumas provided known-fate data on 75 adults, 75 subadults, and 118 cubs. About 30 individuals were captured with dogs, but were not handled due to dangerous positions in trees. Of those pumas not handled, 11 were captured in the *reference* period and 19 were captured in the *treatment* period. Six of 11 pumas not handled in the *reference* period were associated with marked family members (i.e., mothers, siblings, cubs). Likewise, 8 of 19 pumas not handled in the *treatment* period were associated with marked family members.

Reliability of Population Count Methods

The camera grid survey by K. Yeager in treatment year 4 (TY4) spanned 102 days from December 2012 to March 2013. The survey time overlapped 3 months of our capture efforts on the study area from January 1, 2013 to April 18, 2013. Eleven GPS and VHF collared pumas were known to use the survey grid for varying amounts of time, including 7 adult females, 1 subadult female, 2 adult males, and 1 subadult male. During the survey 18 photographs of pumas visiting the sites were acquired, and all 18 of the photographs depicted GPS or VHF collared pumas. The photographed pumas included 1 subadult female (captured 1/15/2013) and 1 subadult male (captured 1/1/2013) that we captured and marked during the camera survey for the first time before cameras subsequently detected them 5 and 3 times each, respectively. In addition, we captured and marked 1 adult male (2/14/2013) for the first time during the camera survey that was not detected by the cameras. Of the 11 collared pumas known to use the grid, 7 were photographed 1 to 5 times each, including 5 adult females, 1 subadult female, and 1 subadult male. Probability of detecting the 11 collared pumas available during the entire survey period was 0.64 (p= 7/11). Because no non-collared pumas were photographed and we detected, captured and marked 3 new pumas before the cameras detected them during the survey, the data indicated that our field methods produced reliable winter population counts.

Puma Population Counts

The number of days we spent each winter and early spring searching for pumas with dogs in each period was similar (*reference* mean=77.2, SD=4.0, range 71-82; *treatment* mean=79, SD=4.8, range 74-86). We believe we had a thorough knowledge of the study area and search routes for reliable counts of the winter population of independent pumas on the study area by *reference* year 4 (RY4) and throughout the *treatment* period. However, in RY5 a state-mandated hiring freeze (in response to economic recession) resulted in insufficient personnel for thorough searches of the study area for a reliable winter count of independent pumas. Therefore, the count in RY5 is biased low, but is still larger than RY4 (Table 2, Fig. 2).

Puma Population Trends

The population of independent pumas increased during the *reference* period without hunting as a mortality factor and the population declined substantially during the *treatment* period when hunting was restored (Table 2, Fig. 2). The increasing population during the *reference period* was the first indication that hunting mortality might have a population affect. The highest number of independent pumas was counted in winter of *treatment* year 1 (TY1) which was preceded by 5 previous years without hunting. The hunting treatment during TY1 to TY3 consisted of a designed 15% harvest rate on the independent pumas with an expectation that the puma population would remain stable or increase. The quota to represent a 15% harvest was 8 pumas based on a model that projected 53 independent pumas expected in TY1 (Appendix II). However, the puma population declined, therefore, a 15% design harvest (actual harvest averaged 16.1% TY1-TY3, Table 3) of independent pumas was not supported for managing toward a stable or increasing population. Because the population declined with a 16.1% actual harvest rate, we wanted to find a harvest that might be sustainable. Therefore, in TY4 and TY5 the quota was reduced to 5 pumas constituting 11-12% design harvest of independent pumas. The population reached a minimum of 42 independent pumas in TY4, a 25% decline (Fig. 3), and was affected mainly by hunting mortality from TY1 to TY3. The population increased slightly in TY5 and was associated with the lower design harvest rate. During the hunting treatment the number of adult pumas declined to the lowest number in TY5, a 34% decline (Fig. 3).

Puma Mortality

The regulations implemented for eliminating sport-hunting as a mortality factor in pumas on the study area in the *reference* period were effective. Of the 32 (21 females, 11 males at risk) adult radio-collared pumas we monitored, 7 adult pumas died; but none from hunting (Table 4). Causes of death were attributed to: 5 natural causes (4 intraspecific strife, 1 unknown), 1 vehicle strike, and 1 depredation control. Of the 22 subadults (8 females, 14 males at risk) providing known-fate data in the *reference* period, 3 died. One male was killed by a hunter after he dispersed from the study area. The other causes of death in subadults were 1 natural cause (trampled by elk) and 1 vehicle strike. Of 55 radio-collared cubs (28 females, 27 males at risk) monitored in the *reference* period, 16 died. Causes included: 13 infanticide, 1 predation, 1 natural, and 1 vehicle strike. In the *reference* period natural causes dominated deaths of adults and cubs, but of the 3 subadult deaths 2 were from human-causes.

In the *treatment* period a total of 35 pumas were killed by hunters on the study area (Table 3), including: 8 adult females (22.8%), 16 adult males (45.7%), 3 subadult females 8.6%, and 8 subadult males (22.9%). This harvest structure was associated with a declining puma population. The ratio of marked to non-marked pumas killed by hunters on the study area before we started our winter capture operations during the *treatment* period was 19:16. Moreover, another 12 radio-collared independent pumas that ranged on the study area were killed by hunters when those pumas moved onto adjacent GMUs open to puma hunting, including: 4 adult females, 7 adult males, and 1 subadult female.

Sport-hunting in the *treatment* period changed mortality for independent pumas (Table 4). Of the 61 adults we monitored (39 females, 22 males at risk), 37 died. Hunting caused 21 adult deaths (14 males, 7 females). Other adult deaths were attributed to: 10 natural (7 unknown probably disease related, 3 strife), 3 vehicle strike, 2 depredation control, 1 illegal kill. Of the 53 subadults (19 females, 34 males at risk) providing known-fate data in the treatment period, 20 died. Eleven were killed by hunters. Other deaths in subadults were: 3 strife, 2 other natural, 1 vehicle strike, and 3 depredation control. Of the 63 radio-collared cubs (27 females, 36 males at risk), 27 died. Mortality causes in the cubs included: 8 infanticide, 4 other natural, 2 vehicle strike, 3 depredation control, and 9 starvation. The 9 cubs starved after the deaths of 5 mothers due to: hunting (2 mothers involving 3 cubs), depredation control (1 mother with 3 cubs), and natural causes (2 mothers involving 3 cubs).

Human caused mortality, particularly from hunting, dominated adult and subadult puma deaths in the *treatment* period. Natural mortality comprised the majority of cubs deaths (15/27*100=55.6%). But, human-caused cub deaths in the *treatment* period increased to 44.4% (12/27*100=44.4%) from 6.2% in the *reference* period.

In addition to these deaths revealed by the radio-collared cubs, we observed deaths of 4 entire litters on the day we entered nurseries to examine cubs for the first time. These cubs were not part of the radio-collared cub population used to model or estimate cub survival (see below in Puma Survival, *Cubs*). One litter of 3 nursling cubs starved to death in the *reference* period after the mother was killed for depredation control. In the *treatment* period, we observed that three entire litters died: one litter with 2 cubs and one litter with ≥1 cubs died of infanticide. A third litter with ≥1 cub died due to black bear predation.

Puma Survival

Adults

Our adult survival sample included 75 radio-collared individuals, with 32 monitored in the *reference* period and 61 monitored in the *treatment* period. The most parsimonious survival model included gender interacting with period (i.e., *reference*, *treatment* periods, indicating a treatment effect) as factors that best explained variation in adult puma survival rates (Table 5). The evidence ratio using AIC_c weights (w_i) indicated very strong support for the top model with 10.10 times the support of the second-ranked model with gender in an additive effect with period. Moreover, >4 ΔAIC_c separated the top model from the second-ranked model. The remainder of the models in the 8 model candidate set had weak to no support. Clearly, hunting-caused mortality negatively affected adult male and female puma survival, and was particularly strong on adult males. Adult male survival declined from 0.96 in the *reference* period to 0.40 in the *treatment* period, and adult female survival declined from 0.86 to 0.74 in those respective periods (Table 6).

Subadults

Our subadult survival sample included 75 individuals with known-fates: 22 in the reference period and 53 in the treatment period. For subadult pumas the modeling results indicated period as an important factor influencing survival as indicated by the two top-ranked models ≤2 ΔAIC_c points (Table 7), which together accounted for 0.77 of the model weights (w_i). Evidence ratios using AIC_c weights (w_i) indicated the top-ranked model with interaction of gender with period had weak support for the best model with 1.7 times the support of the second-ranked model with period (i.e., genders combined). Subadult males were strongly negatively affected by hunting-caused mortality, similar to adult males. Subadult male survival declined from 0.92 in the *reference* period to 0.43 in the *treatment* period. However, subadult female survival indicated no substantial change from 0.63 to 0.70 with overlapping 95% CIs in those respective periods (Table 7). The second-ranked model *S*period (with genders combined) had reasonable support as the best model (i.e., 1.0567 $\Delta AIC_{c,}$ w_i=0.28631) for explaining variation in subadult survival which declined from 0.84 (95% CI 0.60, 0.95) in the *reference* period to 0.52 (95% CI 0.37, 0.66) in the *treatment* period (Table 8).

Independent pumas

Hunting-caused mortality in the *treatment* period was the single-most important cause and it was strongly additive. Had hunting mortality been strongly compensatory, the population of independent pumas was expected to be relatively stable or increase (consistent with the *reference* period population trend), meaning hunting mortality would have compensated for other causes of mortality. Adequate immigration would have also compensated for some mortality. But, this was not the case. The number of independent pumas increased in the *reference* period without hunting mortality and it declined substantially in the *treatment* period in association with hunting as the major cause. Moreover, other independent pumas that ranged on and off the study area were killed by hunters and other causes of mortality continued to materialize in the *treatment* period, including natural and other human causes, all of which contributed to population decline.

Cubs

Our cub survival sample included 118 cubs: 55 cubs from 32 litters in the *reference* period, 63 cubs from 45 litters in the *treatment* period. Modeling results indicated that hunting treatment as a factor explaining puma cub survival variation was less conclusive. This age stage was not expected to be directly affected by hunting mortality because cubs were not legal game. The two top-ranked models indicated period as a factor that influenced cub survival (Table 9) and together accounted for 0.54 of the model weights (w_i). Evidence ratios using AIC_c weights (w_i) indicated the top-ranked model with an interaction of gender with period had weak support as the best model with 1.6 times the support of the second-ranked model with period. Moreover, the top model had 1.7 times the support of the third-ranked continuous survival model with no treatment effect. The top model was separated from the next two models by ≤1.0174 ΔAIC_c, and with the evidence ratios this indicated that all 3 models had substantial support as best models for explaining the variation in cub survival. The top model with gender interacting with period indicated no substantial change in female cub survival between the *reference* (0.34) and *treatment* (0.39) periods (Table 5). But male cub survival declined from 0.71 to 0.30 in those respective periods. The second-ranked model (*S*period) also had substantial support as the best model to explain changes in cub survival (females and males combined) which declined from 0.50 (95% CI 0.34, 0.66) in the *reference* period to 0.34 (95% CI 0.22, 0.48) in the *treatment* period (Table 10). The third-ranked model $S_{(.)}$ (i.e., no treatment effect, combined genders) estimated the cub survival rate 0.41 (95% CI 0.31, 0.52) for the entire study duration. Note: *c*-hat (i.e., over-dispersion parameter) has yet to be estimated for cub survival, and adjustments will be made if necessary.

Puma Reproduction

Adult female pumas on the Uncompahgre Plateau produced litters of cubs between the months of March to September, spanning the early spring to early fall seasons. Data on 66 birth dates revealed that births increased rapidly in May and June, peaked in July, followed by a slight decline in August and a rapid decline in September. No live births were detected in the months of October, November, December, January, or February (Fig. 4). Assuming a 92 day gestation period (Anderson 1983, Logan and Sweanor 2001, this study), the distribution of birth months indicated that puma breeding activity spanned the months of December to June, with a rapid increase in February and peaking March through May.

We estimated gestation for 17 litters by 13 females based on GPS- or VHF- location data of females with prospective sires that produced minimum and maximum estimates. Gestation lengths averaged 90.4_{min}-91.8_{max} days (SD_{min}=2.6, 95% CI_{min} 89.1, 91.6; SD_{max}=1.0, 95% CI_{max} 90.7, 92.8). Birth intervals for 18 adult females that produced 33 litters averaged 18.5 months (SD=5.9, 95% CI 16.4, 24.4). We estimated the age of 13 adult females when they produced their first litters based on estimated ages (n=11) or known-ages (n=2) of pumas at previous captures and nipple characteristics (i.e., tiny, pink or white color) and associated reproduction histories. The average age at first litter was 32.2 months (SD=8.4, 95% CI 27.6, 36.8, range=21-48). This meant those females conceived at the average age of 29.2 months (SD=8.4, 95% CI 24.6, 33.8, range=18-45) assuming an average 92 day gestation period.

Litter sizes were determined for 26 litters produced by 14 females in the *reference* period where we were reasonably certain we counted all the cubs in nurseries when the cubs were 26 to 42 days old. Likewise, we determined litter sizes for 21 litters of 16 females in the *treatment* period for nursling cubs 25 to 45 days old. Average litter sizes for each period estimated using linear mixed models were 2.76 (SE=0.1806, 95% CI 2.41, 3.12) for the *reference* period and 2.38 (SE=0.1972, 95% CI 1.99, 2.76) for the *treatment* period. Change in the average litter sizes in the two periods was small and the averages were not significantly different because the 95% confidence intervals on the slope for period included zero. The male:female sex ratio for 72 nursling cubs in the *reference* period was 41:31 and was not significantly different from an expected 1:1 ratio (χ^2=1.388, 1 d.f., 0.10<P<0.25). Similarly, the 27:22 sex ratio for 49 nurslings in the *treatment* period was not significantly different from an expected 1:1 ratio (χ^2=0.51, 1 d.f., 0.25<P<0.50). With all the cubs pooled from both periods, the sex ratio 68:53 was not significantly different from parity (χ_c^2=1.860, 1 d.f., 0.10<P<0.25).

Fecundity, defined here as the proportion of adult female pumas giving birth each year, was determined for *reference* period years 2 to 5 (i.e., RY2-RY5) when we radio-monitored 12 to 13 individual females per year and *treatment* period years 1 to 5 (i.e., TY1-TY5) when we radio-monitored 15 to 17 individual females per year. Average fecundity per year for each period estimated using generalized linear mixed models were 0.63 (SE=0.068, 95% CI 0.49, 0.75) for the *reference* period and 0.48 (SE=0.057, 95% CI 0.37, 0.59) for the *treatment* period. The average fecundity rates for the periods were not statistically different because the 95% confidence interval for the slope included zero. However, a lower average fecundity of 0.48 over 5 years was expected to produce a substantially lower population growth (~6% less per year) than an average fecundity of 0.63 in our deterministic discrete time model (Appendix II) with zero harvest and all other population parameters being equal. Therefore, decline in fecundity from the *reference* to *treatment* periods was biologically significant, especially because it occurred with lower survival rates.

Management Implications

1) A 15% design harvest (actual harvest averaged ~16%) of independent pumas in this population manipulation was associated with a substantial population decline in 3 years. Up to ~12% harvest of independent pumas may be sustainable.
2) Human causes of mortality, especially hunting, affected survival of independent pumas in the *treatment* period.

3) Natural causes of mortality were undetected by managers, as were some vehicle strikes and illegal killing.
4) The GMU puma management unit structure inadequately fitted the scale of hunting-caused mortality due to the movements of pumas beyond GMU boundaries.

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Prepared by: ________________________

Kenneth A. Logan, Wildlife Researcher

Table 2. Count of pumas based on numbers of known radio-collared pumas, visual observations of non-marked pumas, harvested non-marked pumas, and track counts of suspected non-marked pumas on the study area during *reference* years 4 and 5 (RY4, RY5) and *treatment* years 1-5 (TY1-TY5). Also indicated * is the population projection for RY5 due to lack of a reliable count (see text), Uncompahgre Plateau study area, Colorado.

Period & Year	**Study Area region**	**Adults**		**Subadults**		**Cubs**		
		Female	**Male**	**Female**	**Male**	**Female**	**Male**	**Unknown sex**
RY4	East slope	10	4	3	4	4	4	7
	West slope	6	4	2	0	1	2	2-3
	subtotals	16	8	5	4	5	6	9-10
	Total Independent Pumas = 33: 21 females, 12 males. Cubs = 20-21							
RY5	East slope	11-13	5-6	2-4	0-1	2	5	5
	West slope	9-10	4	1-2	1	3	2	4
	subtotals	20-23	9-10	3-6	1-2	5	7	9
	Total Independent Pumas = 37, *45							
TY1	East slope	16	10	1	2	1	3	4-8*
	West slope	14	10	0	3	3	3	5-6
	subtotals	30	20	1	4	4	7	9-14
	Total Independent Pumas = 56: 31 females, 25 males. Cubs = 19-24							
TY2	East slope	15	5	3	2	7	9	7
	West slope	15	7	2	3	2	5	9
	subtotals	30	12	5	5	9	14	16
	Total Independent Pumas = 52: 35 females, 17 males. Cubs = 39							
TY3	East slope	13	4	1	3	4	2	4
	West slope	14	5	3	5	1	2	6
	subtotals	27	9	4	8	5	4	10
	Total Independent Pumas = 48: 31 females, 17 males. Cubs = 19							
TY4	East slope	15	4	3	2	4	4	3
	West slope	10	5	3	0	2	5	6
	subtotals	25	9	6	2	6	9	9
	Total Independent Pumas = 42: 31 females, 11 males. Cubs = 24							
TY5	East slope	10	6	3	6	6-7	2	2
	West slope	13	4	1	1	1	3	11-13
	subtotals	23	10	4	7	7-8	5	13-15
	Total Independent Pumas = 44: 27 females, 17 males. Cubs = 25-28							

Table 3. Pumas killed by hunters on the study area during the *treatment* period, Uncompahgre Plateau, Colorado.

Treatment Period Year	Adult Female	Adult Male	Subadult Female	Subadult Male	Quota	Actual No. pumas killed	No. of Independent pumas in count	Percent harvest of Independent pumas
TY1	2	5	1	1	8	9	56	16.1
TY2	0	5	2	1	8	8	52	15.4
TY3	3	1	0	4	8	8	48	16.7
TY4	2	2	0	1	5	5	42	11.9
TY5	1	3	0	1	5	5	44	11.4
subtotals	8	16	3	8				

Table 4. Causes of death in adult, subadult, and cub pumas in the *reference* and *treatment* periods, Uncompahgre Plateau, Colorado.

Reference Period						
Adults (21F,11M at risk	**Females Number**	**Females Percent**	**Males Number**	**Males Percent**	**Total Number**	**Total Percent**
Strife	3	50	1	100	4	57
Other natural	1	16.7	0	0	1	14.3
Vehicle strike	1	16.7	0	0	1	14.3
Depredation control	1	16.7	0	0	1	14.3
Illegal kill	0	0	0	0	0	0
Hunting	0	0	0	0	0	0
Subadults (8F,14M at risk)						
Strife	0	0	0	0	0	0
Other natural	1	50	0	0	1	33.3
Vehicle strike	1	50	0	0	1	33.3
Depredation control	0	0	0	0	0	0
Illegal kill	0	0	0	0	0	0
Hunting	0	0	1	100	1	33.3
Cubs (28F,27M at risk)						
Infanticide	9	75	4	100	13	81.3
Predation	1	8.3	0	0	1	6.2
Other unknown natural	1	8.3	0	0	1	6.2
Starvation	0	0	0	0	0	0
Vehicle strike	1	8.3	0	0	1	6.2
Depredation control	0	0	0	0	0	0
Illegal kill	0	0	0	0	0	0
Hunting	0	0	0	0	0	0

Table 4. Continued

Treatment Period						
Adults (39F,22M at risk)	**Females Number**	**Females Percent**	**Males Number**	**Males Percent**	**Total Number**	**Total Percent**
Strife	3	14.3	0	0	3	8.1
Other natural	7	33	0	0	7	18.9
Vehicle strike	2	9.5	1	0	3	8.1
Depredation control	2	9.5	0	0	2	5.4
Illegal kill	0	0	1	6.7	1	2.7
Hunting	7	33	14	93.3	21	56.8
Subadults (19F,34M at risk)						
Strife	1	25	2	12.5	3	15
Other natural	0	0	2	12.5	2	10
Vehicle strike	0	0	1	6.2	1	5
Depredation control	1	25	2	12.5	3	15
Illegal kill	0	0	0	0	0	0
Hunting	2	50	9	56.2	11	55
Cubs (28F,36M at risk)						
Infanticide	3	30	5	29.4	8	29.6
Predation	0	0	0	0	0	0
Other unknown natural	0	0	4	23.5	4	14.8
Starvation	5	50	4	23.5	9	33.3
Vehicle strike	0	0	2	11.8	2	7.4
Depredation control	2	20	1	5.9	3	11.1
Illegal kill	0	0	0	0	0	0
Hunting	0	0	0	0	0	0
Mauled by dogs	0	0	1	5.9	1	3.7

Table 5. Adult puma survival modeling results, Uncompahgre Plateau, Colorado.

Model	AICc	Δ AICc	AICc w_i	Model Likelihood	Number Parameters	Deviance
{S(gender*period)}	396.9874	0	0.84055	1	4	162.0375
{S(gender+period)}	401.613	4.6256	0.0832	0.099	3	168.6719
{Sgender*year}	402.1608	5.1734	0.06327	0.0753	14	147.0023
{S{period)}	405.339	8.3516	0.01291	0.0154	2	174.4044
{S(gender)}	416.7478	19.7604	0.00004	0	2	185.8131
{S(.))}	417.3778	20.3904	0.00003	0	1	188.4475
{S(month)}	509.8345	112.8471	0	0	108	53.2893
{S(gender*month)}	716.7591	319.7717	0	0	216	0

Table 6. Puma adult, subadult, and cub annual survival rates, estimated from top model *S*gender*period for each stage, Uncompahgre Plateau, Colorado.

Adults (≥24 months old)				
Period	**Gender**	**Average annual Survival estimate**	**Lower 95% CI**	**Upper 95% CI**
Reference	Female	0.8599	0.7153	0.9345
	Male	0.9593	0.7459	0.9942
Treatment	Female	0.7415	0.6324	0.8230
	Male	0.3971	0.2232	0.5692
Subadults (13-24 months old)				
Period	**Gender**	**Survival estimate**	**Lower 95% CI**	**Upper 95% CI**
Reference	Female	0.6303	0.2320	0.9058
	Male	0.9233	0.6106	0.9893
Treatment	Female	0.7026	0.4247	0.8832
	Male	0.4272	0.2651	0.6071
Cubs (1-12 months old)				
Period	**Gender**	**Survival estimate**	**Lower 95% CI**	**Upper 95% CI**
Reference	Female	0.3439	0.1727	0.5683
	Male	0.7132	0.4393	0.8875
Treatment	Female	0.3906	0.2048	0.6147
	Male	0.3020	0.1606	0.4944

* Over-dispersion parameter c-hat has to be estimated for the cub survival data.

Table 7. Subadult puma modeling results, Uncompahgre Plateau, Colorado.

Model	AICc	Δ AICc	AICc w_i	Model Likelihood	Number Parameters	Deviance
{Sgender*period}	190.0683	0	0.48562	1	4	39.4874
{Speriod}	191.125	1.0567	0.28631	0.5896	2	44.5933
{Sgender+period}	192.1299	2.0616	0.17323	0.3567	3	43.5771
{S.}	195.2243	5.156	0.03687	0.0759	1	50.7065
{Sgender}	196.6757	6.6074	0.01784	0.0367	2	50.1439
{Smonth*period}	206.5767	16.5084	0.00013	0.0003	24	13.888
{Smonth*period*gender}	266.4878	76.4195	0	0	48	0

Table 8. Subadult puma survival rates estimated with second-ranked model *S*period, females and males combined, Uncompahgre Plateau, Colorado.

Subadults (13-24 months old)			
Period	**Survival estimate**	**Lower 95% CI**	**Upper 95% CI**
Reference	0.8371	0.5991	0.9464
Treatment	0.5152	0.3685	0.6594

Table 9. Cub puma modeling results, Uncompaghre Plateau, Colorado.

Model	AICc	Δ AICc	AICc w_i	Model Likelihood	Number Parameters	Deviance
{Sgender*period}	317.1119	0	0.3335	1	4	309.0458
{S{period}	318.0671	0.9552	0.20686	0.6203	2	314.0473
{S{.}	318.1293	1.0174	0.20053	0.6013	1	316.1227
{Sgender+period}	319.4672	2.3553	0.10272	0.308	3	313.4276
{S{gender}	319.6242	2.5123	0.09496	0.2847	2	315.6045
{S{gender+Birthmonth}	320.8604	3.7485	0.05118	0.1535	3	314.8208
{Sgender*period}+birthmonth}	324.8551	7.7432	0.00695	0.0208	5	314.7558
{Smonth*period}	326.3474	9.2355	0.00329	0.0099	24	276.2961
{Smonth*period*gender}	367.9388	50.8269	0	0	48	263.5538

Table 10. Cub puma survival rates estimated with second-ranked model *S*period, females and males combined, Uncompahgre Plateau, Colorado. Over-dispersion parameter c-hat has to be estimated for the cub survival data.

Cubs (1-12 months old)			
Period	**Survival estimate**	**Lower 95% CI**	**Upper 95% CI**
Reference	0.4999	0.3363	0.6635
Treatment	0.3392	0.2187	0.4849

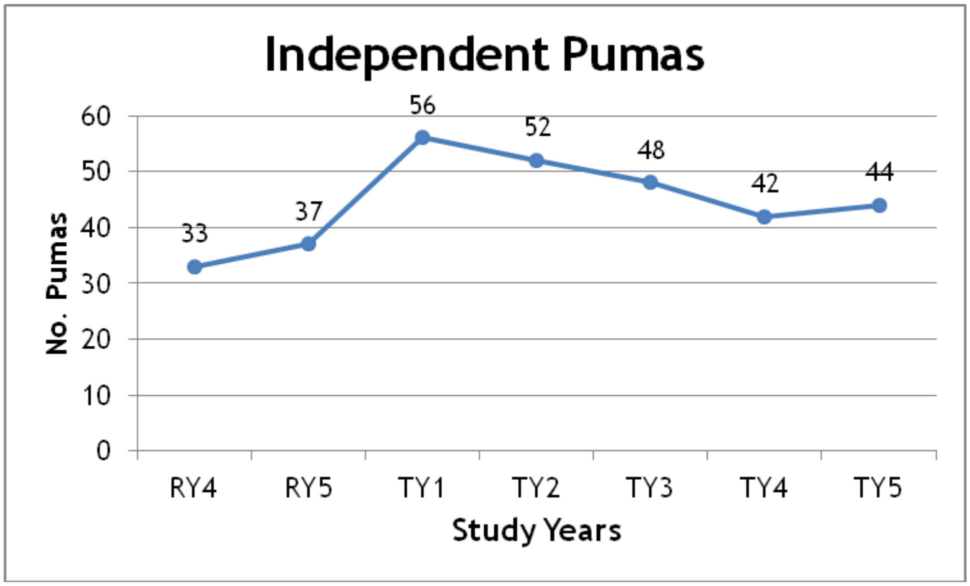

Figure 2. Counts of independent pumas, Uncompahgre Plateau, Colorado. Counts in RY4 and TY1 to TY5 are from ground surveys and capture efforts. The count for RY5 is biased low because capture efforts were insufficient due to lack of personnel to thoroughly search the study area (see text).

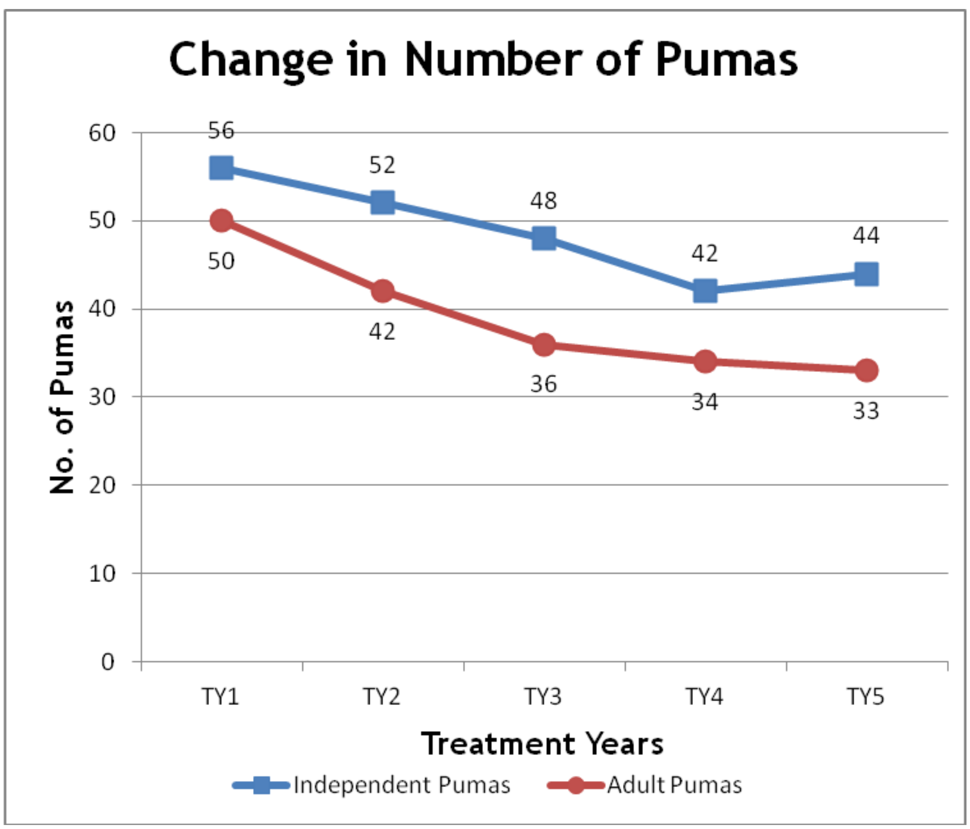

Figure 3. Change in numbers of independent and adult pumas, Uncompahgre Plateau, Colorado.

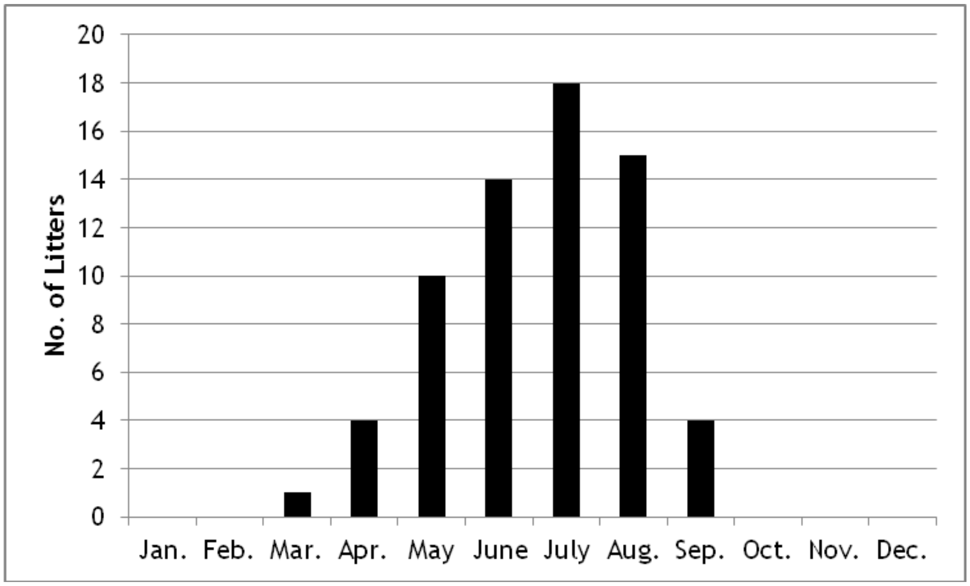

Figure 4. Puma births (black bars) detected by month from May 19, 2005 to September 30, 2014 (*n* = 66 litters of 33 females; 60 litters were examined at nurseries when cubs were 25-45 days old, 4 litters were confirmed by tracks of ≥1 cubs following GPS- and VHF-collared mothers and 2 litters by remains of cubs of 2 GPS-collared mothers when cubs were ≤45 days old, Uncompahgre Plateau, Colorado.

APPENDICES

Appendix I. ACUC Capture and Handling Forms and Protocols

File # ________________ Revised Date ______________
(ACUC Secretary will supply)

COLORADO PARKS AND WILDLIFE ANIMAL CARE AND USE COMMITTEE (CPW ACUC) FORM FOR REVIEW OF NEW RESEARCH PROJECTS

1. Principal Investigator (s): Dr. Kenneth A. Logan, Mammals Researcher, CPW.

   Phone: 970-252-6013(o) or 970-275-3227(c) E-mail: ken.logan@state.co.us

2. All investigators (including all individuals involved in implementing research:
   Principal investigator Ken Logan (CPW), all CPW technicians and other houndsmen.
3. Location of facility or study area: The study area is on the Uncompahgre Plateau in western Colorado in areas west and southwest of Montrose. The study area is the South Uncompahgre Plat (in Mesa, Montrose, Ouray, and San Miguel Counties). The study area includes about 2,200 km^2 c southern halves of GMUs 61 and 62, and about 155 km^2 of the northern edge of GMU 70. The are bounded by state highway 348 at Delta, 25 Mesa road and Forest Service road FS503 to Nucla, sta highway 97 to state highway 141 to state highway 145 to Placerville, state highway 62 to Ridgewa U.S. highway 550 to Montrose, and U.S. highway 50 to Delta.

4. Beginning date: December 1, 2008.

5. Ending date: April 1, 2014.

6. Title of project: Assessing Effects of Hunting on a Puma Population on the Uncompahgre Plateau, Colorado.

7. Species of animal (s): *Puma concolor*

8. A study Plan or Prospectus describing each research or pilot project is required with this form. Is the Study Plan attached? Yes _X_ No ___

9. Rationale for use of this animal model:
   a. Explain why other models (e.g. nonanimal models, in vitro techniques) are inappropriate.
      This study pertains specifically to puma population dynamics and attendant effects of hunting off-take. It is intended to provide wildlife managers with useful information for the management of pumas in Colorado.
   b. If not a species specific study, why is this the most appropriate species for this research?

   c. If capturing wild animals for pen research, why is this source most appropriate?

10. <u>If the study will use wild animals, describe capture and transport methods</u>:
Please refer to the attached study plan *Puma capture and marking* (pages 13-15, 18, 24) and the *Mountain Lion Capture and Handling Guidelines*.

11. <u>Location of capture</u>: Pumas will be captured on the study area described in question 3 above.

12. Indicate number of animals to be used _20-30 pumas/year_. Provide a brief justification (or page reference in Study Plan) for sample size selected:
Please see study plan sections *Puma capture and marking*, *Population monitoring*, and *Population Size* (pages 13-19).

13. By signing this form, you are verifying that all persons involved in this project are adequately trained. Briefly describe the training process(es) and list personnel responsible for animal care and handling: K. Logan, S. Young, have all been trained in and have directly captured, immobilized, and sampled pumas. All new technicians and houndsmen will receive training on pumas by principal investigator Ken Logan.

14. Provide a detailed description of the procedures and manipulations of animals, including an end point (if necessary) at which animals will be removed from experiment or be euthanized. (If described in Study Plan or Prospectus, provide reference page numbers.) If administration of anesthesia and /or surgery is part of the procedure, identify who will perform these tasks:
Please see study plan section *Puma capture and marking* (pages 13-19).

15. Are the levels of pain and suffering, stress, discomfort, deprivation, etc., to be experienced by experimental animals greater than normally associated with handling, administration of therapeutics by commonly used methods, or routine venipuncture?
Yes __ No _X_
If answered yes, attach a detailed justification and indicate here the date of search, some of literature search, date range searched, and key words and combination of key words searched to document the lack of alternative methods:

16.
Will pain and suffering be controlled? Yes ____ No ____ N/A _X__
If answered no, attach a detailed justification.
Describe how pain and suffering not associated with routine handling will be controlled.
a. Methods and dosage of anesthesia to be used: N/A

b. Methods and dosage of analgesia to be used: N/A

c. Methods and dosage of tranquilization to be used: N/A

17. The attending veterinarian **<u>must</u>** be consulted when planning projects where handling of any animal will occur. Do this prior to submitting this application. Date consulted_________

Does the proposed project include planned euthanasia of animals? Yes _____ No _X__

Signing below assures that all investigators have reviewed the CPW ACUC Euthanasia Guidelines and that investigators will use appropriate methods for humanely destroying animals involved in their study. Please indicate the criteria for and methods of euthanasia to be used in this study:

Date: ________ Signed: ___________________________________
Principal Investigator

18. Signing below assures that the planned research does not unnecessarily duplicate previous research on the subject and species proposed for study.

Date: ________ Signed: ___________________________________
Principal Investigator

Appendix II. Puma Population Model and Simulations

Research on the Uncompahgre Plateau Puma Project from December 2004 to July 2007 provided estimates of puma population structure and parameters for a model-based approach developed by CPW biometrician Dr. P. Lukacs and Mammals Researcher Dr. K. Logan to examine options for the design of the remainder of this research, and as a preliminary assessment of the CPW puma management assumptions.

Puma Population Modeling

Our puma population projections for the study area involved an age-structured, deterministic, discrete time model. The additive puma population model structure is:

N_{t+1} =
Adult Females = $(S_{AF} * N_{AFt} + S_{SF} * N_{SFt}) * (1 - H_{AFt+1})$ +
Adult Males = $(S_{AM} * N_{AMt} + S_{SM} * N_{SMt}) * (1 - H_{AMt+1})$ +
Subadult Females = $((r * S_C * N_{Ct}) * (1 - H_{SFt+1})) * PI_{SF}/E_{SF}$ +
Subadult Males = $(((1 - r) * S_C * N_{Ct}) * (1 - H_{SMt+1})) * PI_{SM}/E_{SM}$ +
Cubs = $L_{\tilde{y}} * AF_R * N_{AFt+1}$

Terms:
N_{AFt+1} = Number of adult females at year t+1.
N_{AMt+1} = Number of adult males at year t+1.
N_{SFt+1} = Number of subadult females at year t+1.
N_{SMt+1} = Number of subadult males at year t+1.
N_{Jt+1} = Number of juveniles at year t+1.
S = Survival rate for each specified sex and age stage.
H = Proportion of the harvest rate comprised by each sex and age stage (e.g., 0.28 harvest rate * 0.40 adult females).
r = Proportion of the subadult population that is female (e.g., 0.5; 1-0.5 = proportion of males).
PI/E = Ratio of progeny + immigrants/emigrants.
$L_{\tilde{y}}$ = Average litter size.
AF_R = Proportion of adult females giving birth to new litters each year.

Basic assumptions of the model include: 1) expected puma population projections and annual rates of increase (i.e., lambda) are conditional on the assigned puma population structure and demographic estimates, and 2) no density dependent responses are built into the model. In reality, density dependence probably operates in puma population dynamics, with competition for food regulating adult female density and competition for mates regulating adult male density (Logan and Sweanor 2001).

We parameterized the model with data gathered on the pumas on the study area during the previous 3.7 years. The starting population was the *minimum count* of pumas and attendant estimated sex and age structure made during November 2007 to March 2008 (Table AI.1). We assumed that all individuals were present in the population during that entire period. No mortalities of independent pumas were detected. But, one radio-collared subadult male emigrated by March 19, 2008. Population parameters included: estimated rates of reproduction and sex and age-stage specific survival, which included data to July 2008 (Table I.2). Some sex and age-stage specific estimates of survival (i.e., adult male, subadult male, subadult female) came from the literature (Table 2), because our current sample sizes (i.e., number of individuals and years) were not adequate for realistic estimates (i.e., estimates from our data were 1.0 for adult males and subadults). We did not use actual rates in the literature where estimates involved the pooling of data on sexes and age stages, and where sample sizes for age stages were not presented (e.g., Anderson et al. 1992). In addition, the ratio of progeny and immigrant recruits to emigrants as a model input was from the literature, because such data were scarce and does not exist for Colorado (all references in Table AI.2). We preferred using the population characteristics and parameter estimates gathered in the current research effort, because this is the puma population we intend to manipulate to assess current CPW puma management strategies.

Table AI.1. Minimum puma population count on Uncompahgre Plateau study area, Colorado, November 2007 to March 2008 (RY4). The minimum count involves counting all radio- and GPS-collared pumas, all other marked pumas, and all presumably unmarked pumas detected on the study area during the period. Presumed unmarked pumas could be marked with ear-tags and tattoos. Their tracks and movements could be separated from movements of radio- and GPS-collared pumas. Or they exhibited evidence that could separate them from other local marked pumas from their tracks (i.e., distinguishable by sex, number of cubs and/or relative size of cubs varied).

	Adults		**Subadults**		**Cubs**		
Region	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Unknown sex**
East slope	10	4	3	4	4	4	7
West slope	6	4	2	0	1	2	2-3
Totals	16	8	5	4	5	6	20-21
	Total Independent Pumas = 33[a,b]						

[a] Of the total, 23−24 (70−73%) independent pumas were marked and 9-10 (27−30%) were assumed to be unmarked.

Table AI.2. Summary of preliminary puma population model parameter estimates obtained from the Uncompahgre Plateau Puma Project and from the literature on puma.

Survival

Sex and age stage	**Estimate**	**Reference**
Adult Female	0.87	Estimated average annual survival rate (*n* = 2 years) for 11−13 adult females on Uncompahgre Plateau study area.
Adult Male	0.91	Estimated average annual survival rate (*n* = 8 years) for adult males in a non-hunted New Mexico puma population (Logan and Sweanor 2001:127-128). Estimated annual survival rate (*n* = 2 years) for 5−9 adult males on Uncompahgre Plateau study area was 1.00.
Subadult Female	0.80	Estimated subadult female survival in New Mexico (0.88, *n* = 16; Logan and Sweanor 2001:122) adjusted downward for potential lower survival for pumas 12-24 months old on Uncompahgre Plateau (0.642, *n* = 14 females and 10 males combined, life stages not known or described in Anderson et al. 1992:53). Survival of 7 radio-collared pumas (5 males, 2 females) in the subadult stage in the current Uncompahgre Plateau puma study is 1.00.
Subadult Male	0.60	Estimated subadult male survival in New Mexico (i.e., 0.56, *n* = 9; Logan and Sweanor 2001:122) adjusted upward for potential slightly higher survival for pumas of both sexes 12-24 months old (i.e., 0.642) on Uncompahgre Plateau (Anderson et al. 1992:53). Survival of 7 radio-collared pumas (5 males, 2 females) in the subadult stage in the current Uncompahgre Plateau puma study is 1.00.
Cub	0.50	Estimated cub survival rate (*n* = 38 cubs combined sexes), on Uncompahgre Plateau study area. This survival rate is applied to the model starting with the expected number of cubs from birth in RY5.
	0.90	Estimated cub survival for cubs ≥7 months old, and is applied to RY4 cubs only, because the minimum count of pumas in RY4 was tallied when most cub mortality had already occurred. Survival of cubs ≥7 months old in the literature is about 0.95 (Logan and Sweanor 2001). Here, a more conservative 0.90 is used in this model.

Reproduction

Parameter	**Estimate**	**Reference**
Adult age	2+ years	Assume all females 2 years old and older are adults (Logan and Sweanor 2001: 93-94).

Litter size	2.81	Average litter size for 21 litters on the Uncompahgre Plateau study area = 2.810 ± 0.9808*SD*; litters were examined when the cubs were 26 to 42 days old.
Secondary sex ratio observed at nurseries	1:1	Secondary sex ratio was 33:26 for 21 litters examined at 29 to 42 days old on the Uncompahgre Plateau study area (not significantly different from 1:1, ($X^2 = 0.8305 < 3.841$, $\alpha = 0.05$, 1 d.f.). This result supported Logan and Sweanor 2001:69, $n = 148$).
Proportion of adult females producing new litters each year	0.65	Proportion of adult females giving birth each year (n = 3 years for n = 12, 13, 12 females), Uncompahgre Plateau study area. Proportion for a non-hunted puma population in New Mexico was 0.50 (Logan and Sweanor 2001:98).

Progeny + Immigrant Recruits/Emigration Ratio

Parameter	Estimated Ratio	Reference
Subadult female	1.02	No data for pumas in Colorado exists. Assume the ratio of female immigrants to emigrants = 1.02. This ratio is consistent with estimates for a New Mexico puma population that functioned as a source (Sweanor et al. 2000).
Subadult male	0.94	No data for pumas in Colorado exists. Assume the ratio of male immigrants to emigrants = 0.94, (i.e., male immigration is half of emigration). This ratio is consistent with estimates for a New Mexico puma population that functioned as a source (Sweanor et al. 2000).

Results of Puma Population Simulations

Expected minimum population sizes for independent pumas for RY5 and TY1 conditional upon the number of independent pumas counted in Reference Year 4 (RY4) and the model input parameters and assumptions (given in Tables AI.1 and AI.2).

Table AI.3.

	Puma Population Size					**Independent Pumas**	
	Adult		**Subadult**				
Year	**Female**	**Male**	**Female**	**Male**	**Cub**	**Total**	
RY4	16	8	5	4	20	33	count
RY5	18	10	9	8	33	45	projected
TY1	23	14	8	8	42	53	projected

Appendix III. MOUNTAIN LION HUNTER SURVEY

MOUNTAIN LION HUNTER SURVEY

EXPERIMENTAL LION HARVEST UNCOMPAHGRE PLATEAU STUDY AREA- GMUs 61, 62, and 70

Hunter Name: ____________________ License No.: _____________________CID No.: _____________

1. Please circle the days on which you hunted (please count partial days hunting as full days)

November: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30

December: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31

January: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31

2. Name the drainages and mesas where you hunted ____
____
____

3. Did you hunt with hounds? YES or NO (circle one)
4. Did you hunt with an outfitter? YES or NO (circle one)
5. Do you consider yourself to be a SELECTIVE hunter or a NON-SELECTIVE hunter? (read explanation below, then circle one)

A SELECTIVE hunter is one that purposely is hunting for a specific type of legal lion, such as a male, large male, or large female, and therefore attempts to distinguish between male and female tracks, large and small males or females before taking the animal, and is willing to pass up lions that are detected from tracks or when treed. A NON-SELECTIVE hunter is one that intends to take whatever legal lion is first encountered or caught, with no desire for sex or size.

6. What was the sex of the lion that made the **first** set of tracks you encountered that were less than one day old?
FEMALE ☐ MALE ☐ Did you pursue the lion to harvest it? YES ☐ NO ☐ *NOTE: Adult & subadult male lions usually have hindfoot heel pad widths greater than or equal to 2 1/16 in. (52mm) wide. Adult & subadult female lions usually have hindfoot heel pad widths less than or equal to 1 15/16 in. (50 mm) wide.*

7. Of the total tracks you encountered that were less than one day old, how many were male (_____) and female (_____) lions? (write number on the blank)

8. How many tracks were of females followed by cubs? _________
9. How many times did you pursue lions with dogs? _________
10. How many times did you tree or bay lions with dogs? _________
11. How many of the lions treed and bayed were males (________), females (________), and cubs (________)?
12. Were any of the lions marked with a visible collar or ear-tags? YES or NO (circle one)
If YES, describe the collar color, ear-tag color and number on each lion and its sex & age (i.e., male or female; adults ≥2 yrs. or subadults ~1-2 yrs.; indicate male or female and adult or subadult for each)
____
13. Describe the non-marked lions you caught (e.g., adult male, adult female, subadult male, subadult female) and list here: ____
14. Did you harvest a lion? YES or NO (circle one)
If YES, what was it? MALE or FEMALE (circle one). ADULT (≥2 yrs.) or SUBADULT (~1-2 yrs.) (circle one)
15. What was the seal number? ____________________
16. Did marks (e.g., collar, ear-tag) on the lion influence your decision to harvest or not harvest the animal? (check one)
☐ TO HARVEST ☐ NOT TO HARVEST ☐ NO INFLUENCE AT ALL
17. Did snow facilitate your harvest? YES if the puma was tracked on snow. NO if the puma was tracked on ground without snow. (circle one)

Compliance

Endangered Species Act

This research will involve trapping mountain lions using hounds, cage traps and snares. It is extremely unlikely that any listed species under the Endangered Species Act will be inadvertently captured. However, in the unlikely event that a lynx or wolverine was captured, we will immediately release the animal unharmed. We will utilize existing roadways on public and private lands to access areas for running hounds and setting traps. Other field work on this project will comprise telemetry monitoring primarily from roads and fixed wing aircraft, minimizing potential for disturbing any listed species. No activities associated with this project pose a threat to the well-being of any listed species in Colorado.

Animal Welfare Act

The project is approved through Colorado Division of Wildlife's Animal Care and Use Committee (Project #08-2004 and #03-2007).

NEPA

This research falls under a Categorical Exclusion as set forth in Title 40, Section 1508.4 of the Code of Federal Regulations (i.e., 40 CFR 1508.4) because the actions in this research do not involve significant environmental impacts.

Other Landscape-Oriented Federal Acts

This research will have no impact on the landscape, and therefore, will not violate provisions of other Federal Legislation governing floodplains and wetlands, historical sites, and prime and unique farmlands.

Americans With Disabilities Act

When hiring personnel as part of this project, qualified individuals will not be discriminated against based on disability. No structures or access points will be constructed as part of this research, and thus accessibility is not applicable.