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MEMORANDUM

Date: November 16, 2020

To: Board of Agriculture members

From: Stephanie Page, Oregon Department of Agriculture

Subject: Summary of Resolution #275 discussion materials

In preparation for our discussion of Resolution #275 (Cougar Management Plan) at the December Board meeting, attached is some information shared by Derek Broman, Carnivore-Furbearer Coordinator with the Oregon Department of Fish and Wildlife (ODFW). One attachment includes some key excerpts from the current state Cougar Management Plan, and the other attachment is a scientific journal article summarizing research conducted in Oregon.

Key points in the attached materials include the following.

- ODFW receives numerous phone calls from concerned citizens regarding cougar-livestock conflicts. Many complaints are handled by ODFW and do not result in a cougar being taken.
- ODFW will continue to use non-lethal methods and public education as a primary tool to address cougar-livestock conflict.
- Some studies have indicated a relationship between intensive cougar removals and an increase in livestock depredation and human-cougar conflicts due to an influx of juvenile males. Male cougars can be associated with damage and it is generally accepted that juveniles of most wildlife species have a higher probability of conflict.
- Regarding relationships between take and conflict, Hiller et al. (2015; attached) used Oregon data to model cougar conflict and suggested that conflict decreased with increasing hunter-harvest or at worst remained constant at low to average cougar densities. Also, complaints are low in areas with historically high harvest and all complaints and cougars taken on damage declined following targeted removals.

DAMAGE AND SAFETY MORTALITIES

The number of cougars killed in Oregon due to livestock damage or human safety/pet conflict has been stable statewide and in eastern Oregon, but has been increasing in western Oregon. The average number of cougars taken annually on damage/safety statewide has increased from 23 cougars per year in 1987-1994, to 121 per year in 1995-2005, and 150 per year in 2006-2016 (Table 8). Over the same time, cougar populations have been increasing and expanding into new areas, some highly susceptible to conflict (e.g. urban, agricultural landscapes). Such is the case in western Oregon (Zone A and Zone B, Table 9) where the majority of Oregon's human population resides and small- and medium-sized livestock (e.g. goats, sheep) (*see* Zone A and Zone B in Chapter IV: Adaptive Management). From 2006-2016, damage and safety mortalities comprise 31% of annual known cougar mortalities (Table 3) and the majority (80%) are the result of cougars killed as a result of causing damage to livestock (Table 8).

Table 1. Number of cougars taken on livestock damage and human safety/pet conflict in Oregon.

Year	Damage	Safety	Total	Year	Damage	Safety	Total
1987	8	2	10	2002	110	26	136
1988	13	3	16	2003	111	28	139
1989	15	1	16	2004	95	28	123
1990	29	3	32	2005	125	28	153
1991	22	4	26	2006	106	26	132
1992	17	3	20	2007	114	21	135
1993	20	7	27	2008	109	23	132
1994	29	11	40	2009	110	31	141
1995	41	22	63	2010	99	25	124
1996	64	34	98	2011	139	23	162
1997	82	20	102	2012	130	46	176
1998	93	20	113	2013	148	24	172
1999	91	39	130	2014	124	27	151
2000	120	27	147	2015	133	23	156
2001	98	27	125	2016	151	18	169

COUGAR COMPLAINTS

Cougar complaints consist of the contacts received by ODFW and USDA Wildlife Services (WS) regarding conflict with cougar. ODFW has been recording complaints for over 30 years, although a standardized reporting system was implemented in 2001. ODFW currently manages complaints in the ODFW Wildlife Damage Database and there have been a few updates to the database with the most recent occurring in 2017.

The Wildlife Damage Database has 18 primary complaint types to describe the particular complaint. The complaint types are grouped into three main categories: Safety, Damage and Other. Cougar complaints primarily fall within the main categories of Damage and Safety. Specifically, complaints concerning damage to livestock and human/pet safety. Livestock complaints include physical injuries and predation of livestock, and concerns for livestock safety in areas where a cougar or cougar sign has been observed. Human safety complaints include concerns for humans where people have encountered a cougar, a cougar or cougar sign is observed in populated areas, or cougars have lost their wariness of humans. Pet complaints are recorded when pets are killed or injured by a cougar or when a cougar or cougar sign has been observed in close proximity to pets. Complaints not readily identifiable in one of these categories are counted as other. Sightings reported to ODFW with no discernable concern expressed by the reporting person are not counted as a complaint. Numerous other details are included in the database including if the complaint was verified, the complaint occurred inside city limits, the complaint was a repeat occurrence, and the estimated cost of pet/livestock loss. All of these additional details aid in quantifying the situation at hand and help determine the appropriate response. ODFW staff evaluates each complaint and respond within established legal and policy frameworks and Appendix G provides a summary of how ODFW responds to complaints. At every opportunity, ODFW provides advice and education to the public to reduce current and future conflict.

Not all complaints can be verified as actual cougar conflicts due to the large number of complaints ODFW receives, staffing limitations, cougars do not always leave detectable sign, and complaints are not always reported in a timely fashion. Even when cougar sign is evident, it often disappears within a day or two because of weather, or activities by other animals, people, or equipment. Therefore, complaints reported to ODFW by the public may not actually involve cougars. However, the increasing use and availability of trail cameras, cell phone cameras, and home security systems are creating much more opportunity for species identification and confirmation.

The majority of cougar complaints reported to ODFW are addressed primarily by providing advice on precautionary measures that reduce risk and future conflict, and providing information on legal provisions that allow for taking the cougars causing the concern. Cougar complaints involving livestock, the primary complaint type (Table 11), are generally addressed by WS in counties that participate in the program, or by landowners or their agents in non-participating counties. The majority of cougar-human safety concerns are not verified and do not result in control efforts. However, verified complaints, where threats to human safety are considered high, are addressed by any combination of law enforcement, WS, ODFW, or ODFW agents (Appendix B). All cougars taken on damage or human safety are entered into the damage database, even if no correspondence occurred prior to the animal being checked in.

Table 2. Cougar complaints by Oregon Cougar Management Zone as reported to ODFW, 2007-2016. Cougar sightings are not included in records. Data as of May 1, 2017 and subject to change as new information becomes available.

Year	Zone A	Zone B	Zone C	Zone D	Zone E	Zone F	Total
2007	156	171	30	20	46	30	453
2008	179	197	37	19	67	16	515
2009	154	172	26	15	46	19	432
2010	181	213	11	13	33	14	465
2011	202	239	13	13	25	8	500
2012	140	200	17	13	30	19	419
2013	132	163	14	13	21	16	359
2014	140	217	12	7	14	14	404
2015	225	161	22	12	16	8	444
2016	233	143	17	11	13	4	421

With the exception of Zone A, cougar complaints are stable or declining across much of Oregon (Table 10). ODFW staff speculates that declining cougar complaints may be due to the local public being familiar with how to live with cougars, they know how to resolve their issue, or they are familiar with their legal options. On the other hand, cougar complaints have been increasing in areas of cougar population growth, where human-cougar interactions are a relatively new occurrence, or the local public is unexperienced with how to live with cougars (e.g. Zone A).

Some studies have indicated a relationship between intensive cougar removals and an increase in livestock depredation and human-cougar conflicts due to an influx of juvenile males (Cunningham et al. 1995, Peebles et al. 2013). Male cougars can be associated with damage (Torres et al. 1996) and it is generally accepted that juveniles of most wildlife species have a higher probability of conflict. However, research results vary and a good deal of uncertainty remains on the topic. Due to higher energy requirements, female cougars with young kittens were more likely to enter urban environments in search of wild or domestic prey in the front range of Colorado (M. Alldredge, Colorado Department of Parks and Wildlife, personal communication). Kertson et al. (2013) studied cougar–human interactions in western Washington and reported that interactions were associated with individual behavior and not necessarily a product of a demographic class. Regarding relationships between take and conflict, Hiller et al. (2015) used Oregon data to model cougar conflict and suggested that conflict (measured by cougars taken on damage) decreased with increasing hunter-harvest or at worst remained constant at low to average cougar densities. Also, complaints are low in areas with historically high harvest (Zone E, Table 10), and all complaints and cougars taken on damage declined following target area removals (Table 12).

Table 3. Cougar complaints by category as reported to ODFW, 2007-2016. Cougar sightings are not included in records. Data as of May 1, 2017 and subject to change as new information becomes available.

Year	Livestock	Human Safety	Pets	Other	Total
2007	169	155	51	78	453
2008	166	236	41	72	515
2009	157	194	37	44	432
2010	167	230	30	38	465
2011	206	217	34	43	500
2012	190	181	36	12	419
2013	194	128	19	18	359
2014	184	172	27	21	404
2015	217	190	27	10	444
2016	222	161	28	10	421

Table 4. Cougar complaints received by ODFW before, during, and after target area implementation where cougars were removed to reduce conflict. Complaints through 2016 were available, therefore quantifying complaints 4- and 5-years post-treatment for target areas ending in 2013 was not possible.

Target Area	Years of Removals	Pre-Treatment			During Removals	Post-Treatment		
		5 Years	4 years	3 years		3 years	4 years	5 years
Beulah	2007-2010	48	39	25	12	13	16	16
Heppner	2007-2009	7	4	4	4	4	4	6
Jackson	2007-2009	642	533	417	199	229	282	351
Steens	2010-2013	5	4	3	1	0	*NA*	*NA*
Ukiah	2009-2013	14	12	9	3	1	*NA*	*NA*
Warner	2009-2013	24	22	13	9	4	*NA*	*NA*
Wenaha	2010-2013	14	11	9	3	3	*NA*	*NA*

COUGAR PLAN OBJECTIVES (Objective 3)

Objective 3: So long as objective 1 is met (statewide cougar population above 3,000 animals), ODFW will proactively manage cougar-livestock conflicts as measured by non-hunting mortalities of cougars taken as a result of livestock damage complaints. ODFW may take management actions to reduce the cougar population.

Assumptions and Rationale

ODFW will give special attention around areas where cougar-livestock conflicts occur, with the overall objective to minimize current and future conflicts. Ranching and farming are important components of Oregon's economy. Addressing cougar–livestock conflict is an essential part of this management plan.

In areas where cougar populations have increased, human populations have expanded into rural and suburban areas, or both, the potential for cougar-livestock conflicts has increased. Dispersing sub-adult cougars compete with mature and established adults and are frequently forced into areas occupied by people with livestock. Such is the current situation in the northern areas of Zone A where new or growing populations of cougars and human development are coming into conflict as measured by cougars taken on livestock damage. However, in many areas of Oregon with long-established cougar populations, cougar-livestock conflict is present yet appears to be stable or declining.

ODFW receives numerous phone calls from concerned citizens regarding cougar-livestock conflicts. Many complaints are handled by ODFW and do not result in a cougar being taken. Technical information, educational material on cougar behavior, and explanation of current laws regarding livestock protection from cougar depredation is commonly provided. It is possible that these efforts and a greater public understanding of how to avoid or reduce conflict has assisted in reduced or stable occurrences of cougar-livestock conflict across the state. Regardless, ODFW will continue to use non-lethal methods and public education as a primary tool to address cougar-livestock conflict.

Cougars rarely cause damage to land or crops; most damage occurs when cougars take or attempt to take livestock. The Damage Statute (ORS 498.012) allows landowners (or lawful occupants) to take any cougar that is causing damage, is a public nuisance, or poses a public health risk on property they own or lawfully occupy, without first obtaining a permit from ODFW. The statute requires a person taking a cougar to notify a person authorized to enforce the wildlife laws immediately. Landowners may kill the individual cougar(s) causing the damage using dogs and/or with the aid of bait (ORS 498.164(3)). Wildlife Services (WS) is contracted and paid by ODFW to conduct cougar control work in Oregon counties with a WS program. Control efforts are closely associated with individual damage complaints, and are designed to take only the animal creating the damage situation. In Oregon counties where WS is not available, landowners or their agents conduct damage control efforts.

Oregon statute permits the take of offending cougars to resolve conflict, but research using Oregon data determined cougar mortalities associated with livestock conflicts increased with increasing cougar population density and decreased with increasing cougar harvest density (Hiller et al. 2015). Reducing cougar population densities may be considered to address cougar-livestock conflict in an area.

Non-hunting mortalities of cougars represent verified conflict and are not as subjective as complaint or sighting reports. Therefore, cougars taken reactively as a result of livestock complaints will be used as an index to measure conflict for Objective 3. Reported complaints will still serve useful in monitoring conflict, especially verified complaints that are confirmed with evidence, but Objective 3 will focus on non-hunting mortalities.

Using running averages reduces the impact of rare occurrences and accounts for changes in populations (cougars, humans) and landscape. The use of running averages is also common in monitoring other big game species in Oregon. Therefore, comparing 3-year averages to 10-year averages of non-hunting mortalities provides a dynamic technique to gauge cougar-livestock conflict in a given area.

Actions

3.1 Continue to monitor complaints and non-hunting mortalities resulting from cougar-livestock conflict.

3.2 Encourage minimizing cougar-livestock conflicts through non-lethal methods:

a) by providing education on cougar behavior to minimize vulnerability of livestock.

b) by discussing alternatives in livestock management to reduce the potential for cougar conflicts.

3.3 Manage for removals of offending individuals or lower cougar population densities in areas with cougar-livestock interactions:

a) by informing livestock owners of their rights to address damage as allowed by Oregon law.

b) by considering additional hunting or control options in those areas where cougar-livestock conflicts are high.

c) by targeting areas for more intensive cougar removal by ODFW employees or agents (Administrative Removals) where cougar-livestock conflicts are the highest.

3.4 Encourage establishment and/or support of active WS Agents in counties with cougar- livestock conflicts:

a) by working with County Commissioners to encourage participation in the WS program;

b) by working with WS and other groups to support WS funding.

3.5 Evaluate new information and techniques used to control cougar-livestock interactions:

a) by monitoring research in other states or federal agencies to identify new cougar damage control options;

b) by supporting research on reducing cougar-livestock conflicts including efforts to model and predict areas of conflict;

c) by adjusting cougar management based on the Adaptive Management findings.

3.6 Manage cougar-human conflicts so that the cougar population and distribution, as indicated by the 3-year average of non-hunting mortalities due to livestock damage, does not to exceed the 10-year average for that same area.

HYPOTHESES TO TEST IN ADAPTIVE MANAGEMENT

Adaptive management has been employed to manage cougar populations at the zone, WMU, and target area levels to meet management goals and objectives. The 2006 Cougar Management Plan identified four hypotheses to test using the adaptive management framework. These hypotheses are still of interest at this time and continued focus is necessary.

Hypothesis 4) Increased cougar mortality near areas of livestock concentrations will reduce cougar-livestock conflicts to desired levels. Criteria to measure conflict will primarily be non-hunting mortality and secondarily number of complaints received.

Findings

One effort applicable to this hypothesis was Hiller et al. (2015) who modeled cougar-livestock depredations using Oregon data and found that increasing cougar mortality through hunting has the ability to reduce cougar-livestock conflict. Also applicable are efforts to reduce cougar numbers to reduce conflict in a target area. The Beulah Target Area (2007-2010) was implemented to reduce livestock depredations (Appendix J). A reduction in complaints and non-hunting mortalities was observed during and following cougar removals. The Malheur River Unit served as a control unit and non-hunting mortalities and complaints remained similar over those same years. The duration of the reduction in conflict is inconclusive as complaints and damage/safety non-mortalities rose slightly but fluctuated in the years following removals. Overall, a decline in conflict has been observed since implementation but it is unknown how much of it is due to the target area.

As non-hunting mortalities and complaints are stable or decreasing throughout much of the state, opportunities to address this hypothesis may be limited in the future. However, opportunities to examine this hypothesis further may arise in cougar Zone A (Coast and North Cascades) and Zone B (Southwest Cascades) where the numbers of cougars taken due to livestock conflict have been increasing for the last decade. In these zones, medium-sized livestock (sheep, goats) are the dominant livestock present and cougar populations have been growing and expanding, creating opportunities for conflict. Logistical issues of small landholdings, the primary factor inhibiting implementation of the Jackson Target area, could be a problem with conducting removals and testing the hypothesis.

This topic is being tested at the time of writing in the East Umpqua Target Area (Cougar Zone B) where non-hunting mortalities due to livestock conflict have been increasing for many years.

Demography, prey abundance, and management affect number of cougar mortalities associated with livestock conflicts

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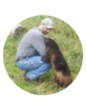

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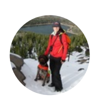

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Research Article

Demography, Prey Abundance, and Management Affect Number of Cougar Mortalities Associated With Livestock Conflicts

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ABSTRACT Balancing the ecological importance of large carnivores with human tolerances across multiple-use landscapes presents a complex and often controversial management scenario. Increasing cougar (*Puma concolor*) populations in the western United States, coupled with an increasing human population and distribution, may contribute to increased numbers of interactions and conflicts (e.g., livestock depredation) with cougars. We assessed county-level factors associated with mortalities of cougars of different sexes and ages resulting from livestock conflicts in Oregon during 1990–2009. Factors included cougar population density, human population density, proportion of the cougar population that were juvenile males, cougar harvest, prey availability, habitat conditions, and climate measured at the county level. We used generalized linear mixed models and quasi-likelihood Akaike's Information Criterion (QAIC) to rank models. Two of 26 models were competitive (ΔQAIC < 4, $\sum w = 0.72$) and both contained cougar population density and cougar harvest density; the second-best model also included proportion of juvenile males in the population. From model-averaging, we determined cougar mortalities associated with livestock conflicts increased with increasing cougar population density (95% CL $= 0.48$–1.37) and decreased with increasing cougar harvest density (95% CL $= -0.58$ to -0.02). An exploratory model including cougar population density, cougar harvest density, proportion of juvenile male cougars, beef cattle density, relative deer density, and all pairwise interactions was equal to the QAIC-top model from the previous set of 26 models. Under a scenario of a high proportion (0.40) of juvenile males, number of cougar mortalities related to livestock conflicts increased 219% when cougar population density increased from 300/10,000 km^2 to 400/10,000 km^2. In contrast, the number of cougar mortalities decreased with increasing harvest when cougar population densities were high (500/10,000 km^2), but we found no relationship at lower cougar population densities. As beef cattle densities increased, the number of cougar mortalities increased substantially (low deer populations), remained relatively low and constant (average deer population), and decreased (high deer populations). Where landowner tolerance to cougar-livestock conflicts is an issue, wildlife managers may provide expertise to reduce conflicts by increasing density of wild ungulate prey, increasing hunter-harvest, and reducing vulnerability of livestock, depending on factors that may be contributing to conflicts.

KEY WORDS cougar, damage management, harvest mortality, livestock, mountain lion, *Puma concolor*.

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Centuries of coexistence of humans and large carnivores has unfortunately included a long history of conflicts. During European settlement in North America until about the 1960s, human responses to conflicts often included the goal of extirpation of large carnivores (e.g., Kellert et al. 1996, Kellert and Smith 2000, Dawn 2002). More recently, knowledge of the complex and far-reaching effects that large carnivores (and their removal) have on ecosystem structure and function has increased (e.g., Ripple et al. 2014) and public attitudes toward large carnivores have become more favorable (Gompper et al. 2015) but remain highly variable or ambivalent for certain species (e.g., cougars [*Puma concolor*]; Kellert et al. 1996). As some large carnivore populations recover across multiple-use landscapes because of conservation efforts, managing conflicts (e.g., livestock depredation, concerns of human safety) to the satisfaction of all stakeholder groups has become increasingly challenging.

With the general elimination of government bounties and unregulated harvest, the recovery of cougars in the western United States has resulted in state wildlife management agencies attempting to adapt and balance ecological, social, political, economic, and recreational considerations, including decisions related to human-cougar conflict management (Patterson et al. 2000, Cooley et al. 2011, Fecske et al. 2011). Conflicts with humans, such as livestock depredation, were the drivers that resulted in widespread killing of cougars during European settlement of North America (Logan and Sweanor 2000). Livestock depredations attributed to cougars may be locally or regionally important and are a central issue in cougar management (Cunningham et al. 1999, Logan and Sweanor 2000). Whether cougars select livestock over wild prey species may depend on prey availability and vulnerability. For example, Cunningham et al. (1999) found evidence that cougars selected for domestic calves in preference to deer (*Odocoileus* spp.) and speculated that deer were less vulnerable to predation. Predation may be an important mortality factor for certain deer populations (Ballard et al. 2001), but whether cougars or other large carnivores respond to large-scale population declines of mule deer (*O. hemionus hemionus*) by selecting for more vulnerable domestic livestock is unknown. We hypothesized that as wild ungulate abundance decreased, particularly as livestock abundance increased, increased vulnerability of livestock would result in increased levels of depredation, and therefore increased numbers of cougars killed in response to conflicts with livestock.

Hunter-harvest may affect sex-age structure and other population characteristics of cougars (Cooley et al. 2009). Increases in cougar harvest may result in population shifts to younger age classes, and therefore potentially higher levels of human-cougar conflicts, as hypothesized by Lambert et al. (2006). In contrast, because of their purported greater vulnerability, high levels of harvest can reduce the proportion of subadults in the population (Anderson and Lindsey 2005). Peebles et al. (2013) suggested that when cougars were subjected to high harvest levels in Washington, high levels of immigration into sink areas resulted, thereby decreasing the age structure and potentially increasing levels of reported complaints and livestock depredations in those areas. Immigrants are more likely to be subadult males as they are more likely to disperse from natal areas and may disperse greater distances than females (Newby et al. 2013, Stoner et al. 2013). Linnell et al. (1999) provided limited evidence that juvenile, old, or sick cougars select more vulnerable prey (e.g., livestock). During 1994, a ballot initiative in Oregon resulted in a management paradigm shift, including less selective (sex-age) and more opportunistic legal harvest methods used by hunters (Oregon Department of Fish and Wildlife [ODFW] 2006). If the proportion of subadult animals increases, the Troubled Teens hypothesis (Stover 2009) predicts that human-wildlife conflicts will increase. Therefore, we hypothesized a direct relationship between the proportion of juvenile males in the population and the number of cougars killed in response to livestock conflicts in a given area.

Factors other than prey availability and population characteristics may also result in livestock losses to cougars. Increases in numbers of cougar-human conflicts have been attributed to habitat fragmentation (e.g., fragmented forest cover) and urbanization (e.g., increasing human density; Torres et al. 1996). We hypothesized that the number of cougars killed in response to livestock conflicts would increase as forest cover decreased and human population density increased, with the highest number of cougars killed in areas with low levels of urbanization and moderate levels of forest cover because these conditions may maximize spatiotemporal overlap between cougars and humans (e.g., Kertson et al. 2011). We did not assume that our hypotheses were mutually exclusive. For example, subadult cougars may include higher proportions of residential areas in their home ranges than adults, although all sex-age classes may use residential areas (Kertson et al. 2013); therefore, a complex relationship involving sex-age population structure, urbanization, and forest cover may exist.

Our objective was to assess factors associated with number of cougars killed resulting from conflicts with livestock production to inform decisions for balancing social and ecological considerations in cougar management. Factors included wild and domestic prey availability, land cover, human population, hunter-harvest, and characteristics of cougar populations. We assessed county-level models that addressed our hypotheses using generalized linear mixed models and model selection. We used county-level data because fine-scale data did not exist to test our hypotheses. In addition, cougars are wide-ranging and usually occur at low densities; therefore, cougar management is generally implemented at relatively coarse spatial scales.

STUDY AREA

Our study area was the state of Oregon, USA, which included diverse topographical features that range in elevation from sea level at the Pacific Ocean coast to >3,420 m in the Cascade Mountain Range. Forested areas in the western third of Oregon included the Coast Range and western slopes of the Cascades dominated by Douglas-fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*) and eastern slopes of the Cascades dominated by ponderosa pine (*Pinus ponderosa*), Douglas-fir, and white oak (*Quercus garryana*; Chappell et al. 2001). Northeastern Oregon included the Blue Mountains, which consisted of western juniper (*Juniperus occidentalis*), ponderosa pine, Douglas-fir, subalpine fir (*A. lasiocarpa*), Engelmann spruce

(*Picea engelmannii*), lodgepole pine (*Pinus contorta*), and western larch (*Larix* occidentalis; Natural Resources Conservation Service 2006). Southeastern Oregon consisted of shrub-steppe vegetation dominated by sagebrush (*Artemsia* spp.) and antelope bitterbrush (*Purshia tridentata*; Chappell et al. 2001, Natural Resources Conservation Service 2006). Mean annual precipitation ranged from about 20 cm in Harney County (southeastern OR) to about 325 cm in Polk County (northwestern OR); mean annual daily temperature ranged from 3.1° C in Klamath County (southcentral OR) to 13.0° C in Douglas County (southwestern OR; Southern Regional Climate Center 2010).

Oregon had an estimated human population of 3.4 million, with the greatest human densities in the Willamette Valley (U.S. Census Bureau 2002*a*). During 1990–2010, the human population in Oregon increased 35% (U.S. Bureau of the Census 1995, U.S. Census Bureau 2010). Estimated statewide cougar populations in Oregon increased 70% from 3,000 in 1993 to 5,100 in 2003, and the number of cougars killed by humans for non-hunting purposes (e.g., damage management, human safety) also increased on average about 14%/year during the same time period (ODFW 2006). Oregon is currently divided into 6 zones for managing cougars (Fig. 1; ODFW 2006). Each zone has an annual quota (i.e., maximum number of recorded cougar mortalities regardless of source) that if reached, results in the closure of the hunting season for cougars in that zone for the remainder of that year. However, zone closure does not prohibit or otherwise affect killing cougars for damage management or human safety (ODFW 2006). During 1995–2011, zone closures occurred for 1 zone in 2001, 2 zones in 2002, and 1 zone in 2011 (ODFW 2006, 2012). A statewide hunting season is open year-round for hunters with the appropriate licenses and permits, but hunters cannot legally harvest spotted kittens or females with spotted kittens (ODFW 2006). A permit is not required by a landowner (or an authorized agent of that landowner) to kill a cougar causing damage (e.g., livestock depredation) or posing a threat to human safety.

METHODS

Data Collection

We used cougar mortality data collected through the mandatory reporting system during 1990–2009, which included individual sex, age class (kitten [<1 yr], juvenile [1–3 yr], adult [>3 yr]), year, and location (county) of cougar mortalities from hunter-harvest and in response to conflicts with livestock (ODFW, unpublished data). Any person killing a cougar for any purpose is required to present the skull, hide, and proof of sex to ODFW for data collection purposes, including tooth collection for aging via cementum annuli analysis (see Schroeder and Robb 2005). We obtained cougar population density and proportion of juvenile males (based on estimated sex-age population structure) estimated at the zone level from a density-dependent, deterministic population model (Fig. 2; Keister and Van Dyke 2002; ODFW, unpublished data); population data were not available at finer spatial resolutions than the zone. This population model uses age-at-harvest data for all hunting and known non-hunting mortalities and population reconstruction methods to back-calculate age and sex structure in previous years. The model makes specific assumptions about non-anthropogenic age-specific mortality and reproductive rates, and assumes that density dependence reduces reproduction and increases age-specific mortality above 75% of the potential maximum population size of about

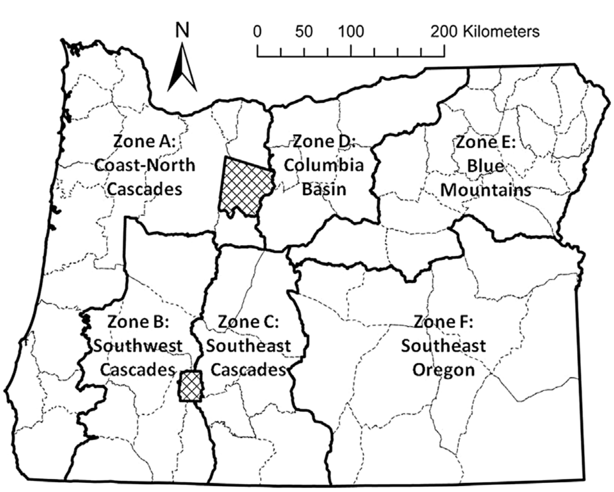

Figure 1. Zone boundaries as defined by the Oregon Department of Fish and Wildlife for the purposes of cougar management in Oregon, USA. Cross-hatched areas include major land areas either not under management jurisdiction of the state wildlife agency (northern area = Warm Springs Indian Reservation) or where hunting was not permitted (southern area = Crater Lake National Park).

Figure 2. Estimated annual proportion of juvenile male cougars in the population for each cougar management zone in Oregon, USA. Zones included A (Coast-North Cascades), B (Southwest Cascades), C (Southeast Cascades), D (Columbia Basin), E (Blue Mountains), and F (Southeast Oregon). Estimates are based on results from a density-dependent, deterministic population model (Keister and Van Dyke 2002; ODFW, unpublished data).

8,000 cougars (Keister and Van Dyke 2002). For our purposes, the assignment of relative population sizes and proportions of juvenile males among zones and across years was important as opposed to the absolute accuracy of this model.

Ungulate species, such as deer and elk, constitute a substantial part of the diet of cougars across their range, including Oregon (Maser and Rohweder 1983, Toweill and Maser 1985, Clark et al. 2014*a*). We used annual ungulate population data collected at the wildlife management unit level (67 units in Oregon). Because we conducted our analysis at the county level, we developed a population index of ungulate abundance at the unit level. Because unit sizes and boundaries differed from counties, we assigned a unit to 1 county when $\geq$95% of that unit was within the boundary of a given county. In other instances, we estimated ungulate abundance for the county as a weighted average of the units based on the proportion the county comprised of each unit. This assumed ungulates were uniformly distributed within the management unit. If data were not available for a given unit during a given year, we used data from an adjacent unit with similar habitat conditions and assumed that it contributed information useful at the county level.

We used annual population abundance indices for 2 allopatric subspecies of deer (mule and black-tailed deer [*O. h. columbianus*]) and 2 allopatric subspecies of elk (Roosevelt [*Cervus elaphus roosevelti*] and Rocky Mountain [*C. e. nelson*] elk) based on population survey data (ODFW, unpublished data; ODFW 2011*a*). For black-tailed deer west of the peak of the Cascade Mountain Range, we used data collected from post-winter road surveys using spotlighting as a relative index (number of deer/km; see ODFW 2008 for field data collection methods). For mule deer east of the peak of the Cascades, we used post-winter data collected primarily from road and aerial surveys (see ODFW 2003*a* for field data collection methods). For Rocky Mountain elk east of the crest of the Cascades, and Roosevelt elk west of the crest of the Cascades, we used a relative density (number of individuals/km^2) based on data collected from post-winter aerial surveys (see ODFW 2003*b* for field data collection methods for elk). Because of differences in collection of data, we developed a standardized population index for each county-year combination. We first averaged indices for 1990 for each subspecies. We then calculated the percentage change by year from the 1990 mean for each county and subspecies and used 1 standardized, independent variable for each species (i.e., deer, elk). We used annual number of beef cattle and sheep by county (number of individuals/km^2) as the available domestic prey (National Agricultural Statistics Service 2011).

Although cougars are distributed statewide in Oregon, vegetation cover may limit cougar populations because cougars appear to select forested areas where prey abundance is high (Seidensticker et al. 1973, ODFW 2006, Jenks 2011). Therefore, we used estimates of the proportion of forest cover at the county level as a metric of relative habitat quality for 2 time periods (1990–2000, 2001–2010; K. Waddell, U.S. Forest Service, Pacific Northwest Research Station, unpublished data). Although these data were temporally limited (i.e., 10-yr periods), we could not obtain similar county-level data from another source. Therefore, we assumed annual changes in forest cover at the county level were limited. We hypothesized that weather patterns across Oregon may also affect cougar-livestock conflicts, because weather could influence domestic or wild prey availability or vulnerability. We used mean maximum temperature (°C), mean minimum temperature (°C), total precipitation (cm), and total snowfall (cm) to characterize annual weather at the county level (Western Regional Climate Center 2008). If a county contained >1 weather station, we selected the weather station with the most complete data set during our study period and nearest the center of that county to represent weather patterns within that county. We used annual estimates of human population by county (U.S. Census Bureau 2002*b*, 2011) to assess potential associations between human population and number of cougars killed for conflicts with livestock.

Statistical Analysis

We centered (subtracted the mean) and rescaled (divided by the standard deviation) all independent variables to improve model convergence (Draper and Smith 1998). To test for multicollinearity among independent variables, we used the Pearson product-moment correlation coefficient (r). If $|r| < 0.70$ for any pair of independent variables, we assumed multicollinearity did not compromise model results. If multicollinearity existed for a pair of independent variables, we did not include both variables in a model.

We modeled the annual number of cougars killed within a county as a result of livestock conflicts on characteristics of the environment and the cougar population. We assumed that the number of mortalities associated with livestock conflicts was a Poisson count variable with discrete events occurring at a constant rate within a county and a year. The expected number of events in county i and year t is $\lambda_{i,t}$. However, to control for variation in county area, we standardized rates across counties using $\lambda_{i,t} = \lambda^a_{i,t}A_i$, where a indicates the rate per unit area and A_i respresents an offset term (Crawley 2007). We used generalized linear mixed models with a log link function to examine how variation in features of each county and year affected $\lambda_{i,t}$. We included cougar population density in the county (cougars/km^2) in all models because we assumed the number of animals killed was related to population density. An alternative hypothesis was that a specific number of cougars will be killed regardless of population density. This hypothesis was implicit in models containing cougar population density as a predictor; if the estimated coefficient of cougar population density was not different from 0, then the rate of cougar mortalities was independent of cougar population density.

We constructed a set of a priori models, including the null model (offset only), by logically selecting from a total of 13 independent variables (each as a fixed effect) to test hypotheses regarding the dependent variable. We treated county and year as random effects on model intercepts (including the null model) and we included cougar population density as a fixed effect in all models (excluding the null model) because we expected this independent variable to be highly explanatory (e.g., Peebles et al. 2013). We assessed overdispersion of data by estimating the variance inflation factor ($\hat{c}$) based on the chi-square goodness-of-fit test and visually examined residuals for an indication of systematic lack of fit using the global model. We used quasi-likelihood adjusted Akaike's Information Criterion (QAIC) for overdispersed data and ranked models based on model complexity and fit (Burnham and Anderson 2002). If model selection uncertainty affected interpretation of model results (i.e., assessment of ΔQAIC values, weight of evidence [w], log-likelihood values; Burnham and Anderson 2002), we model-averaged across all models to reduce effects of any uninformative parameters (Burnham and Anderson 2002, Arnold 2010). Finally, we calculated the z-score (i.e., model-averaged maximum-likelihood estimate divided by the model-averaged standard error) for each independent variable to standardize parameter estimates and assess their relative values as model parameters. We used Program R (v3.1.1, www.r-project.org, accessed 18 Oct 2014) for all statistical analyses. Unless noted otherwise, we assessed parameters using 95% confidence limits (LCL = lower, UCL = upper).

Post Hoc Analysis

We conducted 2 post hoc analyses following model selection and averaging, which we acknowledge may be considered a form of data dredging; however, we took this approach to fully investigate data to increase our understanding of complex systems (Burnham and Anderson 2002). First, we conducted a post-hoc analysis to address the alternative hypothesis that a small, fixed number of cougars cause depredations. We removed cougar population density from each of the a priori models described above and re-ran the analysis. If the alternative hypothesis was valid, then this set of models would have a top model with QAIC scores close to or better than the top model in the a priori model set.

Second, we constructed an exploratory model using only independent variables with coefficients that were significant ($\alpha = 0.05$) in ≥ 1 of the top 13 models ranked during the model selection process. We also included all pairwise interactions of these independent variables in the exploratory model. We then used 10-fold cross validation (Picard and Cook 1984) to evaluate the exploratory model based on predicted and observed values and QAIC to compare this model with the full model set previously constructed.

RESULTS

The annual number of cougar mortalities related to livestock conflicts averaged 22.0 (SD = 5.2) during 1990–1994; mean number of mortalities increased by 14.0/year during 1996–2000, then varied but averaged 101.8/year (SD = 8.7) during 2001–2009 (Fig. 3). Our full data set contained information on 756 county-year combinations. After deleting county-year combinations with missing data for 1 or more independent variables, our subset for analyses contained 400 county-year combinations.

Of the independent variables selected for model construction, no pairs exhibited multicollinearity. We constructed 26 models, including the global and null models, to test our hypotheses. The global model describing number of cougar mortalities showed moderate overdispersion ($\hat{c} = 3.6$) and residuals showed no systematic lack of fit. Because data were moderately overdispersed, we used QAIC to rank models. The top 13 models had ΔQAIC < 7.64 and $\sum w = 0.96$; only 2 models had ΔQAIC < 2 (Table 1). The top 2 models contained cougar harvest density; cougar population density was included in all models except the null model. We model averaged over the full set to minimize the effect of uninformative parameters. Two model parameters (cougar population density, cougar harvest density) had 95% confidence limits of coefficient estimates that excluded 0 (0.48–1.37 and −0.58 to −0.02, respectively) and z-scores >2, suggesting that these parameters had value (Table 2).

In re-analyzing the 25 a priori models without cougar population density, the best model had a QAIC score 5.5 units greater than the best model in the a priori set, and a log-likelihood score that was greater than all 13 models in the 95% confidence set. Thus, we concluded that cougar population density was an essential independent variable. The same 2 models (cougar harvest density, cougar harvest density + population proportion of juvenile male cougars) were ranked as the first and second QAIC-best models, respectively, confirming the importance of harvest density as an independent variable.

In the second post-hoc analysis, 5 independent variables (cougar population density, cougar harvest density, population proportion of juvenile male cougars, beef cattle density, deer relative density index) differed from 0 ($P < 0.05$) in at least 1 of the top 13 models. Including these variables and 2-way interactions, at $\alpha = 0.05$, 9 fixed effects or interactions were significant (Table 3). This model ranked approximately equal to the top model with ΔQAIC = 0.13.

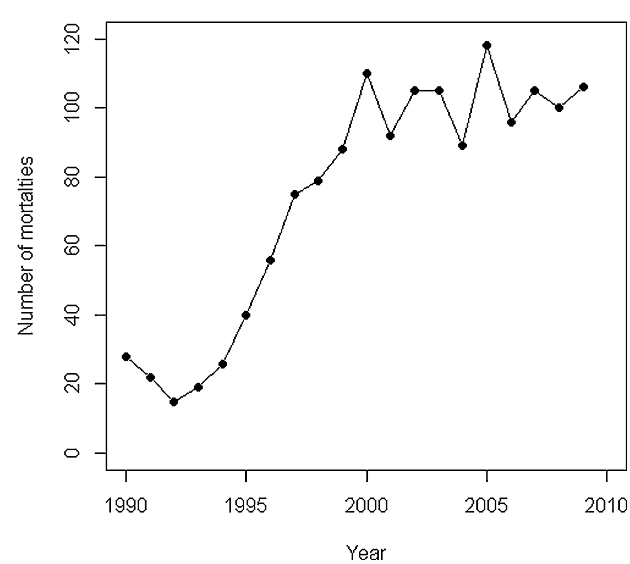

Figure 3. Annual number of cougar mortalities related to livestock conflicts during 1990–2009, Oregon, USA.

Table 1. Model selection results of top 13 models from a set of 26 based on Akaike's Information Criterion using quasi-likelihood adjustments (QAIC; Burnham and Anderson 2002) to predict number of cougars killed/100 km^2, Oregon, USA, 1990–2009, where K = number of model parameters, ΔQAIC = difference in relation to best model within the set, and w = QAIC weight. Data included 400 county-year combinations; all models contained cougar population density as a fixed effect and county and year as random effects on the intercept.

Model		K	ΔQAIC	w
1	Cougar population density + cougar harvest density	5	0.00	0.46
2	Cougar population density + cougar harvest density + population proportion of juvenile male cougars	6	1.11	0.26
3	Cougar population density + cougar harvest density + population proportion of juvenile male cougars + proportion forest cover + human population density	8	4.53	0.05
4	Cougar population density	4	5.51	0.03
5	Cougar population density + cougar harvest density + population proportion of juvenile male cougars + beef cattle density + sheep density + deer relative density index + elk relative density index	10	5.83	0.02
6	Cougar population density + deer relative density index	5	5.86	0.02
7	Cougar population density + population proportion of juvenile male cougars	5	5.98	0.02
8	Cougar population density + proportion forest cover	5	6.44	0.02
9	Cougar population density + beef cattle density + sheep density	6	6.59	0.02
10	Cougar population density + beef cattle density + sheep density + deer relative density index	7	6.78	0.02
11	Cougar population density + human population density	5	7.43	0.01
12	Cougar population density + total annual snowfall	5	7.45	0.01
13	Cougar population density + mean minimum annual temperature	5	7.51	0.01

Using this model, and regardless of the proportion of juvenile males in the cougar population, density of cougar mortalities increased with increasing cougar population density (Fig. 4) with the effect being stronger at greater proportions of juvenile males in the population. Under a scenario of a relatively high proportion (0.40) of juvenile males, when the cougar population density (number of individuals/10,000 km^2) increased 33% from 300 to 400, cougar mortalities increased 138% from 3.2/10,000 km^2 to 7.6/10,000 km^2; a 25% increase in population density from 400 to 500 resulted in a similar increase in mortalities of 139% (7.6/10,000 km^2 to 18.2/10,000 km^2).

Cougar mortalities did not increase as the density of cougars harvested increased when the estimated cougar population was at minimum (30/10,000 km^2) or mean (200/10,000 km^2) values, and remaining independent variables were held constant at their respective mean values (Fig. 5). However, when the estimated cougar population density was at maximum (500/10,000 km^2), the density of cougar mortalities related to livestock conflicts decreased with increasing harvest density. For example, our model predicted a 5-fold increase in harvest density would result in a 60% decrease in density of cougar mortalities related to livestock conflicts.

The number of cougar mortalities as a function of number of beef cattle was relatively constant at about 1.0–1.5/10,000 km^2 over the range of densities of beef cattle when deer density was average (Fig. 6). When deer were more abundant (i.e., 200% increase in deer density index relative to the average), the number of mortalities per 10,000 km^2 decreased 75% between 0 and 10,000 beef cattle/10,000 km^2, and decreased to ≤ 1.0 with densities of beef cattle $\geq 10{,}000$ using the constant maximum for deer density. In contrast, when deer are scarce, the density of cougar mortalities increased sharply with increasing density of beef cattle.

Our evaluation of the exploratory model using 10-fold cross validation resulted in the least-squares equation $y = 0.29 + 0.91x$, where y = observed number of cougar mortalities (from data) and x = predicted number of cougar mortalities (based on cross validation of exploratory model; Fig. 7). Ninety-five percent confidence limits for the intercept and slope were -0.05 to 0.62 and 0.85 to 0.97, respectively, the coefficient of determination (r^2) was 0.67, and the residual standard error was 2.94 with 398 degrees of

Table 2. Model-averaged estimates for each fixed effect to predict number of cougars killed/km^2 associated with livestock conflicts, Oregon, USA, 1990–2009. Estimates are based on independent variables that were centered (subtracted the mean) and rescaled (divided by the standard deviation). Data included 400 county-year combinations and the model contained county and year as random effects on the intercept; LCL = lower 95% confidence limit, UCL = upper 95% confidence limit.

Fixed effect	Estimate	LCL	UCL	z-score
Cougar population density	0.92	0.48	1.37	4.06
Cougar harvest density	−0.30	−0.58	−0.02	2.07
Population proportion of juvenile male cougars	0.04	−0.07	0.15	0.68
Beef cattle density	0.01	−0.04	0.07	0.52
Deer relative density index	−0.01	−0.06	0.03	0.52
Proportion of forest cover	0.03	−0.10	0.16	0.49
Annual mean maximum temperature	0.002	−0.01	0.01	0.46
Sheep density	−0.01	−0.03	0.02	0.43
Annual mean minimum temperature	−0.002	−0.01	0.01	0.40
Elk relative density index	0.003	−0.02	0.01	0.34
Human population density	−0.01	−0.06	0.04	0.31
Total annual snowfall	−0.001	−0.01	0.01	0.27
Total annual precipitation	0.002	−0.003	0.003	0.10

Table 3. Exploratory model estimates for each fixed effect and all combinations of 2-way interactions (represented by :) to predict number of cougar mortalities/100 km^2 associated with livestock conflicts, Oregon, USA, 1990–2009. Estimates are based on independent variables that were centered (subtracted the mean) and rescaled (divided by the standard deviation). Data included 400 county-year combinations and model contained county and year as random effects on the intercept ($\sigma^2_{county} = 2.07$ and $\sigma^2_{year} = 0.03$).

Parameter	Estimate	SE	z-value	Pr(>|z|)
Intercept	−4.35	0.30	−14.47	<0.01
Deer relative density index	−0.41	0.09	−4.43	<0.01
Cougar population density	0.90	0.23	3.87	<0.01
Beef cattle density	0.13	0.08	1.65	0.10
Cougar harvest density	−0.05	0.15	−0.34	0.73
Population proportion of juvenile male cougars	0.02	0.08	0.28	0.78
Beef cattle density:deer relative density index	−0.33	0.07	−4.90	<0.01
Cougar population density:beef cattle density	0.44	0.11	4.05	<0.01
Population proportion of juvenile male cougars:beef cattle density	0.19	0.06	3.03	<0.01
Population proportion of juvenile male cougars:cougar harvest density	−0.22	0.10	−2.21	0.03
Deer relative density index:cougar harvest density	0.15	0.07	2.08	0.04
Cougar population density:cougar harvest density	−0.21	0.10	−2.03	0.04
Cougar population density:deer relative density index	0.13	0.07	1.87	0.06
Cougar population density:population proportion of juvenile male cougars	0.12	0.10	1.14	0.26
Population proportion of juvenile male cougars:deer relative density index	−0.06	0.06	−1.03	0.30
Beef cattle density:cougar harvest density	0.02	0.07	0.23	0.82

freedom. Interpretation suggests relatively small differences in y-intercepts between the least-squares line and $y = x$, and between slopes (i.e., 95% CL did not include 1). An increase of 1 predicted mortality results in 0.91 observed mortalities, indicating that the model is slightly biased high. As the number of mortalities increased, the disparity between predicted and observed mortalities increased (Fig. 7).

DISCUSSION

We confirmed that cougar population density was associated with the number of cougars killed for conflicts with livestock. We also found evidence that only at high cougar population density did the density of cougar mortalities related to livestock conflicts decrease as harvest density increased (Fig. 5). Although we could not provide evidence of a causal relationship, densities of mortalities related to hunter-harvest and to livestock conflicts appear to have an inverse relationship within the limits of our data. In hunted populations, harvest may be a primary mortality factor (e.g., Lambert et al. 2006, Clark et al. 2014*b*), and if harvest mortality is additive, we might expect an inverse relationship between mortality sources. Contrary to hypotheses presented by others (e.g., Peebles et al. 2013), our results indicate that hunter-harvest may be a useful tool in managing conflicts under some circumstances, such as in Oregon. Such differences in conclusions may be related to differences in lengths of study periods, dependent variables examined, independent variables used to test hypotheses, cougar population characteristics, harvest levels, or other factors.

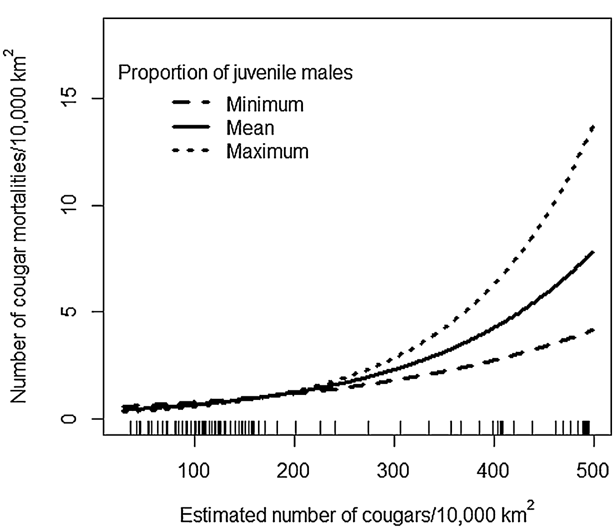

Figure 4. Number of cougar mortalities related to livestock conflicts as a function of estimated population density of cougars, with varying proportions (min. = 0.20, mean = 0.30, max. = 0.40) of juvenile male cougars in the population during 1990–2009, Oregon, USA. Data included 400 county-year combinations (distribution shown as rug plot on x-axis) and all other independent variables were held constant at mean values.

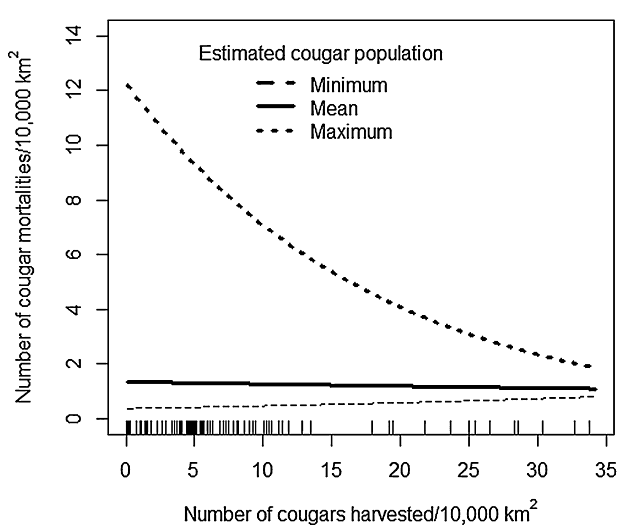

Figure 5. Number of cougar mortalities related to livestock conflicts as a function of harvest density of cougars, with varying density (min. = 30/10,000 km^2, mean = 200/10,000 km^2, max. = 500/10,000 km^2) of cougars in the population during 1990–2009, Oregon, USA. Data included 400 county-year combinations (distribution shown as rug plot on x-axis) and all other independent variables were held constant at mean values.

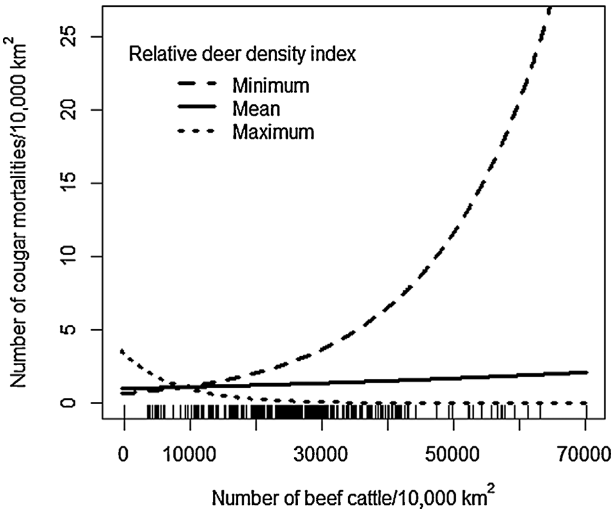

Figure 6. Number of cougar mortalities related to livestock conflicts as a function of density of beef cattle, with varying density indices (min. = 80% decrease, mean = 10% decrease, max. = 200% increase) of deer during 1990–2009, Oregon, USA. Data included 400 county-year combinations (distribution shown as rug plot on *x*-axis) and all other independent variables were held constant at mean values.

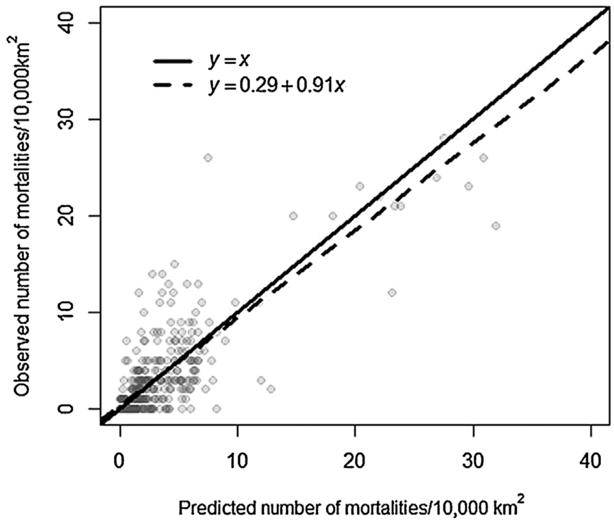

Figure 7. Comparison of observed (data) and predicted (10-fold cross validation of exploratory model) number of cougar mortalities related to livestock conflicts during 1990–2009, Oregon, USA. Data included 400 county-year combinations.

Under relatively low densities of beef cattle (e.g., <2.0/km^2), the number of cougar mortalities associated with livestock conflicts was generally low during our study regardless of deer density (Fig. 6). Similarly, Teichman et al. (2013) reported that low cattle densities (0.3/km^2) did not influence cougar-human conflicts in British Columbia. However, with relatively low deer densities, the number of cougar mortalities increased substantially with increasing density of beef cattle. Although deer densities were based on a relative index and not directly comparable to the absolute densities of beef cattle, the increasing number of cougar mortalities may be associated with decreasing abundance of deer, increasing abundance of cattle, or increased vulnerability of cattle as prey. For jaguars (*Panthera onca*) in Brazil, there was evidence that depredation rates increased with increasing availability of livestock and decreasing availability of caiman (*Caiman crocodilus yacare*) as prey (Cavalcanti and Gese 2010). Similarly, jaguars in a protected park in southern Brazil seemed to increase predation on livestock outside of the park as abundance and diversity of wild ungulates decreased, but livestock depredation rates were still considered low (de Azevedo 2008). In times of prey scarcity, African lions (*Panthera leo*) seemed to select for stray livestock and during times that reduced probability of encounters with humans, thereby balancing benefits with costs (Valeix et al. 2012). With Oregon (and other western states) experiencing long-term declines in mule deer populations (ODFW 2003*a*), an increase in conflicts with cougars may occur in areas with vulnerable densities of beef cattle.

Our model also predicted that as the estimated cougar population density increased, the number of cougar mortalities associated with livestock conflicts increased, and this relationship was affected by the proportion of juvenile males in the population. At a high proportion of juvenile males, we found evidence to expect an increasing number of cougars would be killed for conflicts with livestock as the cougar population density increased (Fig. 4), which is consistent with the Troubled Teens hypothesis (Stover 2009). The usual interpretation of an increase in conflict is that hunter-harvest has altered the age structure of the population (e.g., Lambert et al. 2006, Peebles et al. 2013). The proportion of subadult cougars in harvested samples declines with increasing harvest levels, a consequence of their greater vulnerability to harvest than other age classes (Anderson and Lindsey 2005). Nonetheless, conflicts decreased with increasing hunter-harvest, or at worst remained constant at low to average densities of cougars.

Livestock depredation rates may differ by sex or age for some carnivores. Where radiomarked Eurasian lynx (*Lynx lynx*) in Norway had access to domestic sheep, all male lynx regardless of age killed sheep, killed them more frequently than female lynx, and were responsible for almost all multiple-killing events (Odden et al. 2002). The generally high prevalence of male involvement in livestock depredations seems to hold for many solitary carnivores, perhaps because males typically have larger home ranges, and therefore potentially higher encounter rates with livestock, than females of the same species (Linnell et al. 1999). A positive association had been estimated between carnivore body mass and body mass of their prey (Carbone et al. 1999). Thus, male cougars also may select for larger prey species, such as elk, whereas female cougars may select for deer (Anderson and Lindzey 2002, Clark et al. 2014*a*), so large domestic livestock species may be more vulnerable to male than female cougars. However, number of human-cougar conflicts in British Columbia varied seasonally by sex, with males more frequently reported during summer and females during winter (Teichman et al. 2013). Also, sex of jaguar was not associated with kill rates of livestock in Brazil (Cavalcanti and Gese 2010).

Conflict with livestock following conservation and recovery of large carnivore populations is a complex worldwide management issue (Linnell et al. 1999, Treves and Karanth 2003). As abundance and composition of wildlife species change, predicting predator-prey relationships becomes increasingly difficult. Oregon will be subject to future compositional changes in predator communities and therefore predator-prey interactions, assuming that gray wolves (*Canis lupus*) continue to increase in abundance and distribution within the state (ODFW 2014). Presence of wolves may result in changes in spatiotemporal patterns, reduced predation of certain wild ungulate species, and prey switching by sympatric cougars due to interference and exploitative interactions (Kortello et al. 2007, Griffin et al. 2011). Disentangling the competing hypotheses of relationships among hunter-harvest, predator and prey populations, and human-carnivore conflicts (Treves 2009) can be used to inform policy makers to effectively develop and meet human-carnivore conflict objectives.

MANAGEMENT IMPLICATIONS

Based on our results, several options of varying feasibility may exist for managers and livestock owners to address unacceptably high levels of cougar-livestock conflicts and reduce the number of cougars killed in response to livestock damage. In areas with high densities of cattle and low densities of deer, removing some or all livestock should be considered to decrease vulnerability to depredation, although the feasibility of this option depends on whether this action is logistically or economically tractable for livestock owners. Landowners may also seek guidance from state wildlife agency biologists to assess deer populations and determine whether deer harvest should be decreased, or if large-scale habitat improvements to increase deer populations may be effectively implemented on their properties (e.g., Mule Deer Initiative [ODFW 2011*b*]) to increase prey densities. However, direct research is lacking to assess other potential effects (e.g., increased cougar densities) that may result from increasing prey populations specifically to address livestock depredations by cougars (Laundré and Hernández 2010).

Increasing or redistribution of harvest of cougars can also be conducted if deemed necessary, particularly if harvest can be selective for juvenile males. Hunters using trained dogs correctly identified sex of cougars in the field 70% of the time, but the sex of juveniles may be more difficult to accurately identify than for adults (Beausoleil and Warheit 2015). Proper training of hunters may increase accuracy of pre-harvest identification, potentially increasing the feasibility of this option in states that allow the use dogs to hunt cougars. Although private landowners can attempt to increase cougar harvest by increasing access to hunters, there may not be enough interest from hunters to do so, especially if opportunities to hunt ungulates on those same properties are limited. Because we conducted our analysis at the county level, implementation of the aforementioned options may have to occur across a large spatial extent to be effective, increasing the complexity of implementing several options. Finally, there is limited evidence that increasing levels of lethal removal by trained professionals of cougars in areas with unacceptably high levels of livestock conflicts may reduce those conflicts (Kirsch et al. 2009), although clearly this is not likely to meet objectives of reducing the number of cougars killed for conflicts with livestock.

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