Human-Cougar Interactions: A Literature Review Related to Common Management Questions

Photo: Brian N. Kertson, Washington Department of Fish and Wildlife

Human-Cougar Interactions Science Review Team

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EXECUTIVE SUMMARY

Interactions between humans and cougars (*Puma concolor*) present unique challenges for wildlife managers; reducing occurrences that lead to conflict is a priority for state and provincial wildlife agencies throughout western North America, including Washington. With an increase in management emphasis of human-wildlife conflict resolution, a growing body of scientific literature related to cougar wildland-urban ecology and the factors that contribute to interactions between cougars and people has developed. Based on discussions with the Fish and Wildlife Commission, our 10-member Human-Cougar Interaction Science Review Team assessed both the analytical and ecological merits of current literature, focusing on data and methods, to summarize the current state of knowledge on human-cougar interactions and factors affecting these interactions. We did not use our review findings to provide management recommendations or evaluate/suggest policy alternatives, but we did highlight important information gaps, research needs, and proposed strategies for conducting scientific investigations to benefit managers and policy makers in the future. We used bibliographic lists, keyword searches in research databases, and new literature encountered as citations within papers we reviewed to identify 96 potential studies for review. We evaluated 41 studies that aligned with eight commonly asked questions regarding how various factors contribute to cougar proximity to, and interactions with people. Our review concluded that the roles of cougar removals (Question 1), cougar population size or trajectory (Question 2), the abundance or diversity of prey (Question 3), human population size, distribution, or recreation levels (Question 6), human attitudes (Question 7), and competition with other large carnivores (Question 8) in cougar interactions with people remain uncertain. We found the studies evaluating the efficacy of nonlethal deterrents (Question 4) provided some

evidence that these methods reduce conflict, most notably that flashing lights can reduce interactions in specific situations. Our review of papers investigating the role of landscape characteristics (Question 5) revealed spatial ecology to be the most reliably studied and best understood facet of cougar wildland-urban ecology; study designs in these investigations were also the most rigorous. Most cougar use, and subsequent interactions with people, occur at the wildland-urban interface or in exurban and rural residential settings immediately adjacent because these habitats provide both abundant native prey (deer) and stalking cover, or they retain enough native landcover, connectivity, and prey to support cougar use, but with a human presence at a level that does not substantially deter cougars. We identified only a limited number of informative studies in our review, primarily because many studies did not collect data to specifically address relevant management questions after developing testable hypotheses. Much of the literature we reviewed was derived from *ad hoc* mining of pre-existing data that had been collected for other routine reasons, data were often not assessed for accuracy, and confounding factors were inadequately addressed. Consequently, many factors theorized to contribute to cougar interactions with people require more rigorous investigation. Because wildland-urban systems are complex, and interactions encompass both human and cougar behavior, we recommend the use of long-term studies that incorporate both ecological and anthropogenic factors within a control-treatment design with replicate study sites to address questions with direct management relevance.

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INTRODUCTION

Interactions between humans and cougars (*Puma concolor*) present unique challenges for wildlife managers. Maintaining viable cougar populations is important because cougars are an apex predator whose presence helps to shape ecosystem composition and function through the top-down effects of predation (Ray et al. 2005) and because the public values the diverse and intrinsic benefits cougars provide (Duda et al. 2002). However, cougars can also present a risk to public safety and private property because spatial and temporal overlap with people can lead to negative interactions resulting in the need for an agency response and/or management action (Alldredge and Kertson, in press). Interactions between people and cougars are relatively infrequent (Kertson et al. 2013, Alldredge et al. 2019), but have become more common in many parts of cougar range over the last 30+ years (Sweanor and Logan 2009); human activity has also expanded into wildland portions of the landscape (Radeloff et al. 2018). Small and medium-sized livestock, which are relatively vulnerable to depredation, are also common at the wildland-urban interface (Kertson et al. 2013), and these animals represent potential for conflict (Beausoleil et al. 2008). Consequently, minimizing human-cougar interactions is a management priority for wildlife agencies in western North America (Cougar Management Guidelines Working Group 2005, Alldredge and Kertson, in press), including Washington (Washington Department of Fish and Wildlife 2015).

Wildlife management informed by science is a cornerstone of the North American Model of Wildlife Conservation (Organ et al 2012) and a critical component of effective wildlife management policy (Meffe et al. 1998, Mawdsley et al. 2018). With an increase in management emphasis of human-wildlife conflict resolution, a growing body of scientific literature related to cougar wildland-urban ecology and the factors that contribute to interactions between people and cougars has developed. This body of research is the product of studies completed in diverse wildland-urban environments of North and South America, and researchers conducted many of these investigations with the explicit intent to inform wildlife managers and policy makers. However, the sheer number of studies, their technical complexity, and the challenges associated with disseminating scientific research (e.g., Ribeiro-Soriano and Berbegal-Mirabent 2017) can make it difficult for policy makers to assess their local applicability. Additionally, because human-cougar interactions generate substantial public interest, policy makers frequently hear from landowners, recreationists, stakeholders, and elected officials on what they believe is the most relevant study or research findings to inform policy. This has occurred frequently in Washington; the management of human-cougar interactions have been the subject of considerable debate since the passage of Initiative 655 by voters in 1996 that banned the use of dogs in cougar hunting. Given the Fish and Wildlife Commission and Washington Department of Fish and Wildlife (WDFW) interest in existing science, a 10-member team consisting of both WDFW and external scientists assessed the scientific literature on the interactions of humans and cougars and factors that increase or mitigate risk in landscapes people and cougars use.

The Human-Cougar Interaction Science Review team was created under the guidance of the Chief Wildlife Scientist, Game Division Manager, and Wildlife Program Director. WDFW members were selected whose roles included cougar research and management or who brought unique skills related to the assessment of scientific methods and literature. WDFW sought external (non-WDFW) team members to bring additional perspectives to the work of the team. The primary criterion for external team members was that they had experience with cougar research and management or had strong research design skills or had exceptional quantitative skills. Additionally, WDFW staff interviewed external members to see if they could approach the task of doing a critical review of the science on the topic of human-cougar conflict objectively (i.e., did not already have a fixed view of the literature on the topic).

To meet the Fish and Wildlife Commission's request, we completed a systematic review of peer-reviewed literature and other relevant published reports pertaining to cougar wildland-urban ecology and interactions with people. We identified relevant literature using bibliographic lists developed by science team members and keyword searches in research databases. We then developed a formal review process aided by 8 topical questions. The science review team independently assessed manuscripts and met monthly to discuss and consolidate perspectives on the strengths and weaknesses of the reviewed literature. To assist readers unfamiliar with cougars or the scientific method, we also developed background sections on cougar natural history and foundational concepts of scientific investigation and the peer review process; we also provided definitions of key terms. This review had one primary objective: to assess both the analytical and ecological merits of current literature, focusing on data and methods, to summarize the current state of knowledge on human-cougar interactions and factors affecting these interactions. This review purposefully did not include developing management recommendations or assessing policy alternatives, but the effort included highlighting important gaps in the current body of published science, associated research needs, and proposing strategies for conducting scientific investigations to benefit managers and policy makers in the future.

Cougar Natural History

The cougar is one of the most adaptable and successful large carnivores on the planet. The fourth-largest cat in the world and the second-largest in the western hemisphere, cougars range contiguously from the southern tip of Chile to northern British Columbia, Canada and have adapted to a diverse array of landscapes (Fig. 1). Once considered largely a creature of wilderness, the cougar's secretive nature coupled with broad habitat use (Sunquist and Sunquist 2002) and dietary flexibility (Murphy and Ruth 2009) allow it to occupy diverse ecosystems, sometimes on landscapes people also use (Beier et al. 2010). Prior to European colonization, cougars in North America roamed from the Atlantic to Pacific coasts; however, government-sanctioned bounty programs and the westward expansion of settlement led to extirpation east of the Rocky Mountains, except in south Florida, where a remnant population persisted (Nowak 1976, Nowell and Jackson 1996). Most western wildlife management agencies reclassified cougars as a managed game species by the late 1960's and early 1970's, ending bounty programs initiating management programs designed to sustain recreational hunting opportunities and viable populations as part of ecological communities (Anderson et al. 2009). Self-sustaining cougar populations are now present in Texas, all 11 western states, and 3 western Canada provinces. Cougars are also recolonizing former range in the Midwest, where they have established self-sustaining populations in North Dakota, South Dakota, and Nebraska (LaRue et al. 2012, 2019). Because cougar populations are viable throughout most of their range, they are not listed as a species "of Concern" by the International Union for Conservation of Nature and Natural Resources (IUCN) throughout their range.

In Washington, cougars are classified as a big-game species managed under regulations that prescribe allowable hunting removals, and cougars are managed for population and social stability. In Washington, cougars occupy about 104,000 km^2 of suitable habitat.

Cougars are an obligate carnivore (i.e., their survival requires animal prey) whose distribution is largely governed by the presence of large-bodied, wild ungulates (Sunquist and Sunquist 2002). Deer (*Odocoileus* spp.) and elk (*Cervus* spp.) constitute the bulk of cougar diets in Washington (Cooley et al. 2008; White et al. 2011; Robins et al. 2019) and throughout western North America, but cougars are adaptable and opportunistic predators capable of taking prey ranging in size from small rodents and lagomorphs (i.e., hares and rabbits) to adult moose (*Alces alces*; Murphy and Ruth 2009). Cougars are opportunistic carnivores that mostly prey on larger native ungulates, but domestic animals comprise < 3% of all documented prey items (Moss et al. 2016; Robins et al. 2019; Stoner et al. 2021); depredations of livestock and pets represent the most common form of conflicts with people throughout their range (Beausoleil et al. 2008).

Conducting research on cougars presents unique ecological and political challenges. Cougars are a relatively low-density, solitary, and secretive carnivore with a complex social organization: female space-use is primarily driven by access to prey for rearing offspring and male space-use reflects the maintenance of large, semi-exclusive territories providing access to several breeding-age females (Logan and Sweanor 2009). Consequently, gathering data from enough individual cougars to make statistical inferences about populations with a sufficient level of certainty (i.e., statistical power) requires working across a large area for an extended period (typically, a minimum of 1,500 km^2 for ≥ 5 years). This is labor-intensive, expensive, logistically difficult, and frequently prevents the use of replicate study areas. Scale challenges can further complicate analyses by introducing uninformative variation into analyses because of greater spatial and environmental heterogeneity. Cougar population studies can be particularly challenging because cougars reproduce throughout the year (Sunquist and Sunquist 2002), and populations consist of both resident and transient individuals. Individuals that have been collared may not remain within the study area for the duration of any study. When individuals enter and leave the study area frequently and unpredictably, assumptions of a closed population and equal capture probabilities among individuals are violated (Kendall et al. 1999, Harmsen et al. 2010). Lastly, a lack of political and social consensus also hinders research because stakeholders often embody different interests and desire different outcomes (Mitchell et al. 2018). For example, exploring dynamics of cougars or their prey typically necessitates a control/treatment design using population manipulation achieved through intentional removals or increases or decreases in cougar or ungulate harvest (e.g., Logan and Runge 2021). Manipulating a cougar population for either intentional decline or growth is often controversial despite that it may provide valuable experimental controls and strengthen scientific inference; thus, not infrequently, researchers must employ less powerful observational methods.

METHODS

Literature Search

To identify scientific literature for our review, we started with personal bibliographies previously developed by science team members, searchable research databases, and by adding references from the literature cited in papers under review. We initially combined the team member bibliographies into an initial master list of candidate literature. We then augmented this master list with additional literature identified using keyword searches in the research databases, "Web of Science", "Wildlife and Ecology Studies Worldwide", and "Google Scholar" accessed via the University of Washington Library's online portal (University of Washington 2021) during the week of March 22, 2021 through March 26, 2021. We completed keyword searches using various combinations of the terms, "Puma concolor", "cougar", "mountain lion", "puma", "interaction", "conflict", "depredation", "residential", "urban", and "wildland-urban interface". Lastly, we encountered new literature as citations within papers we reviewed, and we subsequently added these references to our master list. Our approach yielded a final master list of 96 papers, 87 of which reported the results of investigations of cougar ecology and behavior and 9 pertained to public knowledge, perceptions, and attitudes about cougars (Appendix A). The research objectives of the 87 ecological papers and their subsequent applicability to our review varied widely, so we used 5 criteria to assign each paper to one of 4 categories, reflecting their direct relevance to the topics of cougar-human interactions and cougar use of areas with residential development (Appendix B). We also assigned literature to the topical questions guiding our review.

Topical Questions

We did not complete an intensive review of each of the 96 papers on our master list. Instead, we focused our reviews on papers that most closely aligned with 8 commonly asked questions regarding how various factors contribute to cougar proximity to, and interactions with, people. We used topical questions to guide our reviews for 2 primary reasons: 1) the questions allowed us to organize a large and potentially disparate body of information around specific unifying topics with direct management applications and, 2) the questions allowed us to group our reviews in a way that should increase their utility for Fish and Wildlife Commission members, WDFW policy makers, and the interested public. Our 8 topical questions in the order in which the reviews were completed were:

1. Do cougar removals through recreational hunting and/or agency conflict response affect the number or probability of cougar-human interactions?
2. Does the size (N or density) or trajectory of a cougar population affect cougar-human interaction levels?
3. Does the abundance, diversity, and/or distribution of natural prey affect cougar-human interaction levels?
4. Do preventative measures, such as nonlethal deterrence, quality husbandry, and outreach/education/information sharing affect the frequency of cougar interactions with people?
5. Do landscape characteristics (e.g., residential development levels and/or patterns, habitat type, connectivity) affect cougar-human interaction levels?
6. Does the number of people living, working, or recreating in cougar habitat affect the number of cougar-human interactions?
7. Is the number of conflict reports/complaints correlated with actual frequency of conflicts (*i.e.*, is there published evidence that, with no change in real conflict, complaints may increase because of social tolerance or change in human perceptions [e.g., trail or doorbell camera use, news reports, etc.])?
8. Does the presence of other large carnivores, notably wolves, affect cougar proximity to, or the frequency of interactions with, people?

Review Process

To ensure consistent reviews among team members and papers, we applied a standardized framework to guide our analytical and ecological evaluation of each paper. We structured this process to draw upon the different expertise and strengths of science team members to ensure reviews were as thorough as possible. First, we identified and assigned literature for each topical question based on its relevance score and an initial reading by a subset of the group with the resulting list of papers read by everyone. Because we were interested in both the analytical and ecological merits of each paper, we structured our reviews to evaluate the suitability of the assumptions, scale, sampling strategy, data, and associated analysis to meet the specified research objectives and to determine whether the underlying mechanisms purported were consistent with known cougar ecology and behavior. When present, we also identified key limitations, critical issues, and fatal flaws, both methodological and ecological. Based on these criteria, we each made an independent determination of how well the conclusions were supported and the paper's overall contribution for addressing the topical question. As a final step in the process, we met as a group to discuss our reviews and consolidate assessments into a single set of summary notes as the basis for this report. It was relatively straightforward to identify work that was very well done and supported the authors' conclusions; likewise, it was not difficult to identify serious shortcomings in some papers that made the authors' conclusions suspect or equivocal. In many cases, we did not conclude the authors' conclusions were incorrect, simply that the data or analyses were not rigorous enough to have confidence that the authors' conclusions were justified.

Our review of literature relevant to Question 5 represented a slight adjustment in our process because we identified 22 papers to read (Table 1). To manage the increased workload, we assigned each team member the same 7 papers, those considered most directly relevant to the question and 3 additional papers randomly selected from the remaining pool of 15. This ensured each paper was reviewed by 2-or-more team members. The remaining components of the review for Question 5 did not differ from those for the other topical questions.

Definitions

The literature we reviewed is laden with technical terms and scientific vocabulary that may be unfamiliar to policymakers and the public. Because these terms also appear throughout our report, we provided definitions here to assist readers.

Human-cougar interaction classes (adapted from Alldredge and Kertson, in press):

- Sighting - Reported observation of cougar presence (usually visual).
- Encounter - An unexpected and direct meeting between a human and a cougar without physical contact. An encounter, by definition, also is a sighting with the key difference being proximity to a person. It is generally close (< ~100 meters), outdoors, and the person and cougar are clearly aware of one another. Cougar behavior can include fleeing, benign indifference, or aggressive posturing, vocalizations, and approach.
- Depredation - A cougar injures or kills livestock or pets.
- Attack - A human is injured or killed by a cougar; or alternatively, a person is intentionally, aggressively approached and contacted by a cougar, resulting in injury or death of the person.

Landscape classifications:

- Wildland-urban interface - an edge-like habitat where the human-dominated portion of the landscape meets undeveloped, open space.
- Wildland - undeveloped open space consisting of native landcover.
- Exurban - low density, diffuse residential development interspersed with native habitat; most often situated immediately adjacent to the wildland-urban interface.
- Rural - low density, diffuse residential development with an agricultural component; may or may not be immediately adjacent to the wildland-urban interface.
- Suburban - moderate density, clustered residential development often with varying levels of native landcover present, often in the form of greenbelts, parks, and patches of open space; may or may not be situated immediately adjacent to the wildland-urban interface.
- Urban - high density, intensively developed with limited native landcover present; rarely situated immediately adjacent to wildlands instead buffered by suburban, exurban, or rural landcover types.

BACKGROUND ON THE SCIENTIFIC PROCESS

The scientific method in its essence is an empirical approach for making observations about the world, generating hypotheses consistent with the observations, and testing these hypotheses. It includes the principle that our working hypotheses can, and should, be challenged and updated when new data or better methods become available. The scientific method is a framework for learning—one that reduces observer subjectivity and improves our objective understanding of how systems work.

The elusive holy grail in scientific inquiry is to develop a robust understanding of "cause-and-effect" relationships. What drives a system, process, or outcome? Among contributing factors, how big are the effects, and by how much does their influence differ? These are inherently difficult questions because the systems of interest are often complex and affected by numerous factors other than the ones of interest, as well as by random effects.

In the physical sciences (e.g., chemistry, physics) the pursuit of understanding cause and effect is more plausible because controlled experiments can be conducted. In controlled experiments, the researcher can control variation in everything except the explanatory variable of interest, isolating its effect on an outcome. In disciplines such as environmental science, ecology, and wildlife biology, true formal experiments are rare and difficult. Because most phenomena are studied *in situ* (in their natural place), even well-designed studies are fraught with extensive environmental variation, interactions among variables, and variability among potential explanatory variables and outcomes.

The fundamental elements of scientific investigation are the sampling design and data collection, analysis, and interpretation. The usual and preferred approach is to define the design and analysis to fit specific questions before collecting data (Romesburg 1981, Ford 2004). Because conclusions are typically based on samples from populations of interest, rather than all members, representative sampling that prevents systematic bias, is essential.

Statistical methods often require assumptions (e.g., some methods assume a specific data distribution) that vary across methods. One of the few universal assumptions is that errors in measurement of variables are either negligible or are accounted for during analysis. Statistical methods also range from simple to extremely complex. Simple methods include, for example, two-sample tests for equality of means (e.g., do male and female raccoons have similar home range sizes?), tests for linear relations between variables, and tests for pattern (e.g., Are nests randomly distributed or clustered?).

Simple methods are easy to implement, and results are easy to interpret and explain. Most often, however, simple statistical approaches are steppingstones to tackling more substantive questions. Researchers are often interested in more complex questions, such as what environmental factors influence a process (e.g., animal space use or survival?). More complex mathematical models are required when evaluating, comparing, or describing effects of multiple variables (i.e., predictors) on one or more dependent variables (i.e., outcomes). Usually, competing models are evaluated formally using the principle of parsimony (what is the simplest model that can explain the observed data well; akin to Occam's razor).

Complex models are difficult to implement and interpret correctly for numerous reasons. Errors can lead to incorrect or ambiguous conclusions, and such errors have been regularly identified and addressed in scientific literature (Weiner 1995, Cherry 1998, Eigenbrod et al. 2011, Steel et al. 2013, Nuzzo 2014, Parker et al. 2016). Examples would include the following: use of inappropriate tests (including failure to meet test assumptions, or flawed model structure);, convenience sampling, leading to unrepresentative data (Anderson 2001); failure to consider autocorrelation, (i.e., lack of independence of successive observations, Lichstein et al. 2002); inferring causation from correlation (Romesburg 1981, Aldrich 1995); failure to recognize spurious correlations (analytically detecting a relationship between variables that are functionally unrelated); highly influential outliers in data; confounding (when the association between 2 variables is driven by a 3rd variable's influence on both, Roman et al. 2020); prediction beyond the range of supporting data; failure to recognize that 2 variables that each trend through time will automatically be correlated even if they are unrelated; pseudoreplication (misidentifying the sampling unit such that sample sizes and statistical significance are overestimated; Hurlbert 1984); underestimating the experiment-wise error rate (usually by conducting many statistical tests); data dredging (analysis unguided by specific questions in the hopes of finding something of interest; Nuzzo 2014, Parker et al. 2016); and analyses that mismatch the scale of the data with the scale of the underlying mechanisms of interest.

In general, detecting statistically significant ecological effects in research is easier when the magnitude of effects is large, and/or sample sizes are large, and/or chance variability in the data is modest. When any of these are not true, and especially when all of these are not true, it is challenging to generate powerful hypothesis tests, and reliable knowledge remains elusive. Researchers are generally trying to avoid 2 undesirable outcomes: 1) concluding that important differences or relationships exist, when in fact they do not, or 2) concluding that differences and/or relationships do not exist, when they really do. Both are errors, and both muddy attempts to advance our understanding.

A subtle and common issue in published research stems from a phenomenon known as confirmation bias. In simple terms, confirmation bias is the tendency for researchers to find in data what they hoped or expected to find before the study. Confirmation bias is not unique to ecological research; it has been widely documented across a variety of scientific disciplines (Nickerson 1998, Hallihan and Shu 2013, Wilgenburg and Elgar 2013, Betini et al. 2016). Practices that embody confirmation bias include data dredging and repeated data manipulation and reanalysis to turn initial findings of lack of statistical significance into statistical significance. The influence of confirmation bias is subtle, rarely driven by malfeasance, and is a trait of human nature (Peters 2020). The issue of confirmation bias is important, because scientific information is increasingly used in advocacy (Pielke 2004, Lackey 2007), where science may be deemed "good" if it aligns with personal values and can be used to promote specific policy (Mills and Clark 2001). When properly applied, the scientific method properly applied is blind to the outcome; the rigor or weakness of any scientific endeavor is best judged by inherent attributes of the study design, data, analytic methods, and inference.

Research results inform scientific understanding primarily through the peer review process and publication in scientific journals. When a researcher submits a manuscript, a journal editor usually assigns the paper to one of several associate editors to manage the review process, and 2 or 3 anonymous reviewers are selected to review the manuscript. Reviewers often, but not always, offer similar criticisms and assessments of whether the paper is of sufficient merit to be publishable (in their subjective assessment). The associate editor must reconcile reviewer assessments and often asks authors to revise promising manuscripts, sometimes more than once. The associate editor eventually recommends accepting or rejecting the manuscript, and the chief editor renders final judgment. This process is rigorous, but not perfect (Wager and Jefferson 2001, Benos et al. 2007, Pautasso and Schäfer 2009, Horbach and Halffman 2018). Most papers based on rigorous work are eventually accepted, and most papers with technical shortcomings or low potential for impact are rejected, but not always.

Metrics such as a journal's impact factor (Moed and Van Leeuwen 1995) have been used as a proxy for journal excellence and presumed rigor (see also Olden 2007), and more prestigious journals have higher rejection rates (Aarssen et al. 2008). It is not uncommon for papers to eventually be published that were previously rejected elsewhere. A recent and evolving trend is the development of online open access publishing wherein reader subscriptions are not required to access content. Open access "journals" offer rapid "submission to decision" processing and prompt availability of accepted articles. Open access publishing has both been lauded for advantages, such as accessibility (Bjork and Solomon 2012), and criticized for potentially sacrificing quality control for shorter timelines (Haug 2013, Chopin 2018).

Knowledge advances incrementally, as published studies accumulate. Critical review does not end with a paper's publication. Once published, a paper is subject to ongoing interpretation of its importance and rigor as other papers are published on the topic and as the scientific community evaluates the authors' inferences (e.g., Poudyal et al. 2016, Kompaniyets and Evans 2017). This is a fundamental application of the scientific method. One paper reporting findings of significance is interesting, but it takes replicated published work with consistent findings from others to establish confidence that an ecological principle or process is developing into a prevailing theory or theories (Loehle 1987, Johnson 2002). Typically, our understanding evolves with additional work on a topic.

At times, published works on the same topic seem to be in conflict, or at least, the results are ambiguous. For example, considerable work has explored whether predation represents additive or compensatory mortality in ungulates, with varying conclusions (see reviews by Messier 1994, Bowyer et al. 2014). Although flawed research can contribute to such ambiguity, conflicting results are not necessarily incorrect. Rigorous research has demonstrated that effects of predation can vary depending on the types of prey and predators involved, prey densities relative to carrying capacity, and weather (Singer et al. 1997, Brodie et al 2013). In this, and many other examples, environmental context can strongly affect outcomes, adding complexity to understanding ecological processes.

LITERATURE REVIEW FOR TOPICAL QUESTIONS 1-8

Question 1 – Do cougar removals through recreational hunting and/or agency conflict response affect levels of cougar-human interaction?

We identified 7 papers that were relevant to Question 1 (Table 1). Conclusions embodied in these papers about effects of harvest or agency removals on cougar-human interactions were inconsistent across papers, and often equivocal and not well supported. The basic inference offered by Peebles et al. (2013), Teichman et al. (2016), Laundré and Papouchis (2020) and Dellinger et al. (2021) was that cougar removals and interactions were positively associated (i.e., higher harvest is associated with higher conflict levels); in WDFW (2008) and Hiller et al. (2015) greater numbers of removals were associated with fewer interactions, and in Kirsch et al. (2009) no significant effect of cougar removals on human-cougar interactions was detected. Most results were, however, uninformative because papers were based on convenient but questionable data, design flaws, or misapplied methods; the papers offered few compelling insights into the effects of recreational harvest and agency removals on interactions between cougars and people. Well-known errors that lead to underestimation of chance effects were common, increasing the likelihood of producing spurious findings of significance. The papers do, however, suggest potential hypotheses to be tested in future well-designed and appropriately scaled formal research.

The studies were clustered geographically along the west coast of North America with 2 studies completed in California, 2 in Oregon, two in Washington, and one in British Columbia (Table 1). While this distribution provided a good representation of the range of harvest, agency removals, and interaction levels throughout North America, the scales of the independent (i.e., cougars removed) and dependent (i.e., number of interactions) variables frequently lacked ecological justification because they were too coarse or mismatched. The general approach in Peebles et al. (2013), Teichman et al. (2016), Laundré and Papouchis (2020) and Dellinger et al. (2021) was to use routinely assimilated and publicly available management data (e.g., cougar-human conflict reports, cougar harvests, agency removals, human populations, livestock numbers) to construct regression models. Because these data were collected for unrelated, non-research purposes and were not direct, objective measures of biological phenomena, conclusions depended upon interpretations of data by authors, who often overlooked essential considerations. Importantly, key datasets were not validated for accuracy; authors routinely assumed the data were reliable for quantifying factors of interest.

Peebles et al. (2013) assumed cougar abundance was constant in space and time. As part of their design, the authors intended to use a variable on cougar abundance to test for effects of cougar population size on numbers of depredations. However, their cougar abundance variable was derived (i.e., not measured or formally estimated) by simply using a constant estimate of cougar density multiplied by a map of cougar habitat extent. Thus, there was no more information in their estimate of cougar abundance than in their estimate of cougar habitat extent. Cougar abundance was simply the habitat extent rescaled by a constant (cougar density). Because cougar abundance was treated as a variable in their model, but was really a constant, it was not a useful predictor of variation in depredations. Consequently, the authors concluded, with little support, that cougar abundance was decoupled from conflict risks with cougar removals deemed the meaningful predictor of depredations the following year.

Laundré and Papouchis (2020) made questionable assumptions in their design, and their methodology had substantive shortcomings in data assimilation and analysis. The authors misapplied a treatment-control-design (i.e., claimed a treatment-control design was used when it was not), used poorly justified and questionable variables for deer and livestock abundance, modeled phenomena at a statewide scale that no published work has ever suggested operated at that scale (e.g., predation effects on deer), and dismissed general outcomes (e.g., that higher levels of human harvest can reduce cougar numbers) that have been well documented to have occurred in numerous field studies across several states. It appears likely that data dredging was a prominent feature in the analyses of Laundré and Papouchis (2020). An *a priori* advocacy goal dominates the authors' Introduction and Conclusion sections.

Teichman et al. (2016) compiled data at the scale of British Columbia's Development Regions (average = 72,173 km^2) and standardized model covariates at a scale of 10,000 km^2. The authors' primary conclusion was that they detected a positive association between hunting removals and conflict removals, and they implied a causative relationship (i.e., hunting removals raised conflict risks). They did not recognize that 2 variables both trending in time will be automatically correlated even if they are functionally unrelated. It does not matter if they are trending in the same direction with time or oppositely. The fact that they concurrently change over some timeframe will predictably lead to a detectable statistical association. That association may be real or spurious. In this case the analysis does not allow us to conclude with confidence which is true. The scale of this analysis was also not ecologically defensible because multiple local cougar populations are present within the defined analysis units, and the populations are frequently separated by distances or barriers that are traversed by only an occasional disperser, so harvest and interactions should occur independently from one local population to another (i.e., the analysis does not recognize that a cougar removal in a specific area may be very unlikely to be related to a conflict event in a far distant part of the analysis area). The analysis scale is, unfortunately, decoupled from the appropriate scale for the mechanism of interest. The authors also did not attempt to account explicitly for cougar population size in their analyses. Their analyses did not test a viable alternative hypothesis to hunting increasing conflict: increased cougar abundance could logically lead to both increases in harvest and conflict reports. This hypothesis would account for a potential confounding variable.

WDFW (2008) was an internal agency report that also used data that could not be assumed to reliably quantify factors of interest. The report was not peer reviewed, entirely descriptive, applied mismatched scales, and we believe the conclusions should be judged with caution.

Whereas several of the forementioned studies were based on regression analysis, Kirsch et al. (2009) employed a modified form of before-after/control-intervention (i.e., BACI) design in which they attempted to directly manipulate the cougar population in some units (treatment) for comparison to other units with no cougar removals (control). Kirsch et al. (2009), however, did not account for potentially confounding variables, and their supposition that no observed effect was the result of not removing enough cougars was unsupported. However, their application of a BACI framework represents a superior design for investigating effects of cougar removals while also highlighting considerable logistical challenges of implementing such efforts in wildland-urban landscapes.

The presence of substantial design and analytical issues in the regression analyses were the principal reasons the inference provided by the Question 1 studies that used *post hoc* analyses were equivocal. Common analytical issues we identified were a failure to account for interactions or removals steadily increasing or decreasing over the duration of time the data were collected, the use of interchangeable predictor and response variables (i.e., X predicts Y, but Y also predicts X), use of unreliable/poor quality data, applying predictors at an inappropriate scale, and the presence of confounding variables. Each of the regression-based studies we reviewed contained at least 2 of these analytical shortcomings.

While our review represents a critical assessment of the literature relevant to Question 1 and the impact of removals remains unknown, it is important to note these studies do provide some value to cougar scientists and managers. These papers illustrated well the shortcomings common to efforts where broad scale analyses are attempted to explore questions that were derived after data were collected, the data collection was not designed to answer the question, and the data are poorly validated (i.e., cannot be assumed to reach a standard typical of research quality data). The conflicting and counter-intuitive results present within the forementioned studies demonstrates a need for formal research to determine the relationship between cougar population management and interaction levels (including the question of if there even is a relationship); off the shelf analyses may help generate questions for study but are generally poorly suited to definitively answer questions about complex phenomena. We found that the authors of these papers had a very challenging task: making strong inference about poorly understood and complicated relationships with data not well suited to do so; they also did not generally have an opportunity to collect new data that would be needed to address the question.

Question 2 - Does cougar abundance or population trajectory affect cougar-human interaction levels?

Our review of 5 studies relevant to Question 2 (Table 1) did not reveal a consistent relationship between cougar population abundance and numbers of cougar-human interactions. Specifically, Aune (1991), Torres et al. (1996), and Hiller et al. (2015) each concluded that a larger cougar population was correlated with a greater number of interactions, whereas Lambert et al. (2006) reported an increase in the number of interactions during a period of cougar population decline, and Kertson and Keren (2021) did not detect an effect of a 25% increase in the population growth rate on either cougar presence in residential areas or the number of human-cougar interactions. This lack of consistency among the studies is likely a consequence of researchers using different research designs with different limitations: most notably, researchers did not directly quantify cougar population characteristics or did not correctly apply descriptive or *post hoc* regression approaches. For example, Aune (1991) used a descriptive design over a limited temporal period that employed coarse population indices such as harvest success, Torres et al. (1996) applied a simple linear regression with the amount of cougar habitat used as a surrogate for population size, and Hiller et al. (2015) relied on an unvalidated deterministic model that does not account for variability in inputs (Keister and Van Dyke 2002) to quantify cougar abundance for use with correlative models. Regression-based approaches of Torres et al. (1996) and Hiller et al. (2015) suffered from some of the same deficiencies noted previously, including failure to address trends in time series (2 trending variables will be correlated even if they are not functionally related), ambiguity of predictor and response variables, mixing of sampling designs, and in the case of Hiller et al. (2015), the use of an unvalidated, deterministic population model (i.e., Keister and Van Dyke 2002) and data dredging. Lambert et al. (2006) avoided these issues with their data derived from an empirically estimated cougar population growth rate, but they extrapolated that rate to a population scale beyond the appropriate area of inference. They also assumed the reported trend of increasing interaction levels in the broader geographic area (> 30,000 km^2) was representative of the trend at the local scale from which the population data were derived. The issues of mismatched scale and extrapolation were further exacerbated by the study's lack of formal analysis of the relationship between population trajectory and interaction levels.

Kertson and Keren (2021) directly quantified and compared cougar population characteristics and interaction levels within a representative study area in western Washington during 2 independent time periods. This design allowed the authors to account for several potentially confounding variables and focus directly on the effects of increased human population growth. Kertson and Keren (2021) yielded 2 key takeaways relevant to Question 2: 1) a growing cougar population does not necessarily translate into a greater number of interactions because the increased growth rate manifested primarily as subadults with a propensity to emigrate outside of the residential/wildland interface study area to the larger wildland matrix rather than recruiting to the study population and, 2) the effects of cougar population size or trajectory are likely mediated or mitigated by other ecological and anthropogenic factors (e.g., the distribution and abundance of people and prey). Torres et al. (1996) similarly discussed the synergistic effects of cougar population growth and expanding residential development within their exploratory analysis of California interaction levels, whereas Hiller et al. (2015) tacitly acknowledged the complex relationship among interaction levels and the numbers of cougars, people, and livestock in Oregon. However, as Kertson and Keren (2021) noted, their finding of no effect on interactions of an increased population growth rate should be interpreted with some caution because of small sample sizes, uncertainty around estimated population parameters, a lack of replicate study areas, and especially emigration: the actual size of the cougar population changed little over time.

Question 3 - Does the abundance, diversity, and/or distribution of prey affect cougar-human interaction levels?

We identified and reviewed 2 papers relevant to Question 3 (Table 1), and our review concluded the studies provided few reliable insights. Polisar et al. (2003) provided descriptive evidence that cougars preyed upon domestic livestock on cattle ranches in Venezuela when wild prey were readily available. Their management recommendations for South American ranches experiencing felid depredation may have some utility in Washington and other regions. However, the descriptive nature of their study with small sample sizes biased estimates of prey availability and selection, and the lack of details in their methodology, substantially reduced our confidence in their broader conclusions that cougar depredations in upland pastures were related to limited prey availability.

Burgas et al. (2014) also examined effects of prey abundance and diversity on the occurrence of cougar and jaguar (*Panthera onca*) depredations by comparing cattle farms that did and did not experience depredations in northwest Costa Rica using generalized linear mixed models. The authors concluded there was a negative relationship between depredations and prey diversity and abundance. Our review identified a combination of faulty assumptions and design flaws that likely undermined the application of their findings. Specifically, Burgas et al. (2014) did not account for disparate characteristics of farms, nor differences in the distribution and density of cougars and jaguars, used unreliable survey techniques for prey during a single sampling session, did not rigorously confirm the occurrence of felid depredations, and based their findings on P-values (i.e., statistical significance) without quantifying effect sizes (i.e., ecological importance). Even without these issues, their findings were weakened because differences in relative prey abundance and richness were driven primarily by secondary, medium-sized prey, not the availability of large-bodied, primary prey that typically dictate cougar distribution and abundance (Sunquist and Sunquist 2002, Murphy and Ruth 2009).

Although we identified only 2 papers directly relevant to Question 3, it is important to recognize there is a more expansive body of literature on cougar diet and foraging ecology in wildland-urban landscapes. This literature is largely a product of intensive field studies completed in California (Smith et al. 2015, 2016), Colorado (Moss et al. 2016a, 2016b, Blecha et al. 2018), and Washington (Kertson et al. 2011, Robins et al. 2019) (Appendix 1). Three of these studies focused primarily on the effects of human landscape features on cougar behavior and prey use and were subsequently determined to be more appropriately reviewed within the context of Question 5 (Table 1), whereas the remaining studies examined how human distribution and activity influenced cougar prey use in residential areas (e.g., kill rates, handling times, dietary breadth) and were not directly relevant to any of our topical questions. Without an intensive review by our full team, it would be inappropriate to discuss the merits of these studies. It is, however, worth noting that each study demonstrated that cougars in wildland-urban environments routinely eat ungulates and other prey species associated with people, but domestic species constitute a small proportion of cougar diets.

Question 4 - Do preventative measures, such as nonlethal deterrence, quality husbandry, and outreach/education/information sharing affect levels of cougar interactions with people?

We identified 5 papers relevant to Question 4 (Table 1). These papers provided some evidence nonlethal deterrents can reduce interactions in specific situations. Each study focused exclusively on the efficacy of nonlethal techniques to reduce livestock depredations or cougar proximity to people. Researchers evaluated the use of guard dogs (Gonzalez et al. 2012), aversive conditioning (Alldredge et al. 2019), and a variety of audio and visual deterrents (Zarco-Gonzalez and Monroy-Vilchis 2014; Guerisoli et al. 2017; Ohrens et al. 2019). Four of the 5 studies were completed in South America, whereas Alldredge et al. (2019) conducted their study in Colorado (Table 1). The researchers in the South American studies each concluded that nonlethal deterrents provided some benefit for reducing livestock depredations, but the quality of the research designs and subsequent findings varied considerably among studies. The Ohren et al. (2019) paper represented one of the most rigorous studies included in this review. They used a randomized, 2×2 crossover design to demonstrate that flashing lights (i.e., Foxlights®) reduced depredations on alpaca (*Vicugna pacos*) and llama (*Llama glama*) within the Tarapaca region in the altiplano of Chile. The crossover design provides an excellent framework for exploring cause-effect relationships. This study had only minor shortcomings; however, unique animal husbandry practices and landscape characteristics of the study area (e.g., elevation > 3,000 m, plains) may limit the applicability of their findings to other ecosystems. The remaining South American studies employed research designs that mixed and matched descriptive, comparative, and correlative elements that did not yield compelling evidence that nonlethal deterrents reduced livestock depredations by cougars. Consistent issues across these studies included a failure to adequately account for confounding variables, questionable depredation data, small sample sizes, and a reliance on descriptive/qualitative comparisons. Most notably, each study failed to account for potential differences in ranch characteristics, cougar density, or cougar intensity of use between sites that did and did not employ nonlethal deterrents.

The work of Alldredge et al. (2019) was fundamentally different than the other studies related to this topical question. First, Alldredge et al. (2019) represented an opportunistic approach that explored the use of aversive conditioning techniques (e.g., rubber bullets, bean bag rounds, and dogs) to prevent individual cougars from returning to residential areas or engage in future depredations of domestic animals embedded within a much larger research effort. With this design, the individual cougar, not the site being treated, represented the sampling unit. Second, the wildland-urban environment of the Colorado Front Range is very different from the research settings of the South American studies. Although Alldredge et al. (2019) concluded that their aversive conditioning techniques were ineffective, the opportunistic and descriptive research design coupled with small sample sizes prevented definitive conclusions on the topic. An important value of Alldredge et al. (2019) is its identification of important logistical considerations for hazing cougars and their recommendation that future research investigations apply treatments proactively, rather than reactively, to avoid cougars receiving food rewards that may undermine treatment effects.

We concluded the efficacy of nonlethal deterrents to reduce cougar depredations of livestock or proximity to people remains uncertain based on these papers because of research limitations. However, the 4 South American studies each included an important component that improved the design and relevance to applying/evaluating nonlethal treatments. Specifically, each study simultaneously evaluated respective nonlethal deterrent(s) while also actively engaging the local community experiencing conflict. These efforts took several forms and were often multifaceted, reflecting the complex socio-ecological context of conflict issues. We were unable to evaluate the success of these efforts, but we considered this design feature as a strength of these studies nonetheless, largely because investigators stressed the importance of connecting with local citizens to build trust among parties, educating landowners on their role in preventing negative interactions rather than being reactive, improving access to sites and related data, and increasing scientific literacy for successful implementation of nonlethal techniques.

Question 5 - Do landscape characteristics (e.g., residential development levels and/or patterns, habitat type, connectivity) affect cougar-human interaction levels?

We identified 22 papers with relevance to Question 5 (Table 1), revealing spatial ecology to be the most reliably studied and best understood facet of cougar wildland-urban ecology. Researchers employed diverse quantitative methodologies in their studies that yielded remarkably consistent patterns, relationships, and behaviors. The studies we reviewed were not without issues or limitations, but each in its own way benefited from the extensive history of inquiry and rigorous methodologies developed for investigating wildlife spatial ecology over the past 40+ years (e.g., Johnson 1980, Thomas and Taylor 2006). Briefly, the studies we reviewed primarily employed a form of analysis comparing the characteristics of locations that cougars used to those that were not in a logistic or multiple regression framework using a marked individual as the sampling unit (i.e., a Resource Selection Function; Manly et al. 2002). Additionally, the studies provided a highly representative sample of the wildland-urban landscapes in North America and rural settings in the southern hemisphere where interactions occur. The combination of consistent findings produced from both diverse analytical approaches and geographic representation allows us to consider the studies as de facto replicates, substantially increasing our confidence in the validity of their findings. Instead of discussing the merits of individual studies we reviewed, below we present the general understanding of the role of landscape characteristics in the occurrence of cougar-human interactions.

Cougar use of areas with residential development is commonplace, but interactions with people occur infrequently relative to the intensity of this use (Kertson et al. 2011, Alldredge et al. 2019). As residential density increases, cougar use decreases (Kertson et al. 2011; Wilmers et al. 2013; Adams-Knopff et al. 2014; Alldredge et al. 2019) and use of highly urban landscapes is rare (Burdett et al. 2010, Riley et al. 2021). However, cougars will use urban landscapes if patches and corridors of wildland-like habitat are present, sufficiently large enough, and connected to wildlands (Beier 2005; Maletzke et al. 2017; Smith et al. 2019). Accordingly, most cougar use, and subsequent interactions with people, occur at the wildland-urban interface or the exurban and rural residential settings immediately adjacent (Kertson et al. 2011; Alldredge et al. 2019; Klees van Bommel et al. 2020). The wildland-urban interface is used by cougars because the habitat provides both abundant deer and stalking cover, features attractive to cougars (Benson et al. 2016). Exurban and rural residential settings represent interaction hotspots because they retain enough native landcover, connectivity, and prey to support cougar use, but with a human presence at a level that does not significantly deter cougars. This in turn, allows a greater level of spatial and temporal overlap between cougars and people (Burdett et al. 2010, Kertson et al. 2011). Consequently, cougars use these residential areas because habitats that provide a diversity of abundant and vulnerable prey that can be readily exploited are available (Moss et al. 2016; Smith et al. 2016; Blecha et al. 2018; Robins et al. 2019). The studies we reviewed were not designed to determine cause and effect relationships and predator-prey dynamics within wildland-urban environments are complex. Landscape characteristics, prey availability, and cougar movement, however, appear to be intrinsically linked, leading us to conclude that landscape characteristics play a key role in cougar use of residential areas and interactions with people.

The specific landscape covariates included in the models we reviewed varied from study to study, but consistent patterns of greater amounts of forest, increased proximity to wildlands/open space, greater terrain complexity, and fewer houses or greater distance to residential development were consistently associated with increased cougar presence in developed portions of the landscape (Burdett et al. 2010; Kertson et al. 2011; Adams-Knopff et al. 2014; Benson et al. 2016; Jennings et al. 2016; Alldredge et al. 2019; Smith et al. 2019). With the notable exception of distance to residential development, these same landscape features are frequently correlated with the occurrence of cougar-human interactions (Kless van Bommel et al. 2020, Guerisoli et al. 2020). Cougar spatial relationships with specific landscape characteristics are subject to local nuances, however, the consistency we observed leads us to conclude that the use of regression-based space use models of landscape characteristics represent a potentially valuable tool for identifying and mapping areas where cougar-human interactions are most likely to occur.

Question 6 - Does the number of people living, working, or recreating in cougar habitat affect the level of cougar-human interactions?

We identified 2 papers with relevance to Question 6 (Table 1); both examined how cougars responded to increased human recreation levels in park settings. Sweanor et al. (2008) and Penteriani et al. (2016) did not yield definitive inferences on the relationship among human recreation, cougar behavior, and interaction levels. Specifically, Sweanor et al. (2008) did not detect significant shifts in cougar proximity to trails or temporal activity patterns during periods when human recreation was assumed to have increased in Cuyamaca Rancho State Park east of San Diego. The study design yielded straightforward, ecologically relevant data, but making strong conclusions was hindered by the small number of cougars tracked, confounding effects of mule deer distribution, lack of explicit recreation data, and the descriptive structure of the analysis. The result was that the authors were unable to directly link human activity and cougar behavior. Conversely, Penteriani et al. (2016) concluded that increased human recreational levels in North American national parks largely explained increases in cougar, wolf (*Canis lupus*), and bear (*Ursus* spp.) attacks on people. Although these authors demonstrated a clear increase in both human recreation and the number of attacks, the analysis was problematic because of the mismatched locations and scales of attack and recreation data, a failure to account for multiple confounding variables, and the considerable analytical shortcomings present when applying a *post-hoc* regression-based design to multiple systems and species at a continental scale. These issues prevent the determination of a cause and effect relationship between increased human use and conflicts with cougars.

Question 7 - Is the number of conflict reports/complaints correlated with actual frequency of conflicts (i.e., is there published evidence that, with no change in real conflict, complaints may increase because of social tolerance or change in human perceptions [e.g., trail or doorbell camera use, news reports, etc.])?

Although this is a legitimate question with relevance to managers, we were unable to locate any published studies focused on or clearly relevant to the question.

Question 8 - Does the presence of other large carnivores, notably wolves, affect cougar proximity to, or levels of interactions with, people?

We identified and reviewed a single study relevant to Question 8. In an academic thesis, Shores (2020) quantified temporal activity patterns of cougars in northcentral Washington in response to wolves and human hunters within four 64 km^2 camera grids consisting of 16 cameras - 2 grids in areas with documented wolf packs and 2 in areas where wolves were absent or transitory. The author concluded that the presence of wolves in northcentral Washington motivated a shift in cougar activity from night into daylight hours, which increased their potential temporal overlap with people. Although this work may represent a foundation to build future research on, the validity of the conclusions was unclear because of sampling issues in the study design. The wolf/no wolf sampling design was advantageous for quantifying the effects of wolf presence, but the sizes of the camera grids constituted, at most, 33-50% of the average female cougar home range size in Washington, less for males, and only 10% of the average wolf pack territory size. Consequently, each grid sampled a very limited number of cougars, or a very small portion of individual home ranges in areas where wolves were present infrequently. The use of detections as the sampling unit subsequently translated into a limited number of individuals being sampled repeatedly, leading to underestimation of sampling variation and increasing risk of finding spurious relationships. Lastly, the placement of each grid's 16 cameras along trails and roads provided a convenience (i.e., non-random) sample that limited the scope of inference within the broader landscape. Increased temporal overlap between cougars and people would logically increase the risk of their interactions, but definitive conclusions would require that both cougar responses to wolves and interactions with people be simultaneously quantified.

FUTURE RESEARCH NEEDS

Although the literature claiming to inform human-cougar- conflict management questions is not a small number of papers, the relevance of this body of work is limited by equivocal and/or poorly supported inference, with a few exceptions. The principal shortcoming is that there are very few studies where researchers collected data to specifically address relevant management questions after developing testable hypotheses. Much of this literature is based on *ad hoc* mining of pre-existing data that had been collected for other routine reasons (e.g., recreational harvest data), data were often not ground-truthed for accuracy (e.g., do conflict reports reflect real levels of conflict consistently across space and through time?), and confounding factors were inadequately addressed or ignored. Some of the most cited examples also attempted to create variables wherein data were not actually measured and were assumed to not vary (e.g., cougar abundance). Many papers also had stated research hypotheses that were not directly relevant to the central management questions or the variables used did not plausibly describe biological phenomena that they were intended to measure. The literature review revealed several key information gaps that currently hinder an understanding of cougar-human interactions and the ability of wildlife managers to effectively reduce conflict and increase coexistence. Agency and University scientists and their collaborators can address these gaps with research, but only if the studies contain objectives that are directly relevant to management, are well-designed and executed, and are publicly supported by policy makers and stakeholders. The relative scarcity of properly designed studies yielding strong inference in this topic area to date does not mean questions about conflict risks are intractable for research. There are plausible ways to design future research to improve its relevance for wildlife managers, policy makers, and the public. Because wildland-urban systems are complex, and interactions encompass both cougar and human behavior, we emphasize the need for long-term studies that incorporate both ecological and anthropogenic factors within a control-treatment design framework.

Many of the underlying ecological mechanisms that contribute to human-cougar interactions remain poorly understood. For example, what, if any role cougar population characteristics, predator-prey dynamics, and competition with other large carnivores play in cougar-human interactions represent potentially important, but understudied components in wildland-urban systems. Cougar-human interactions obviously do not occur without people, so the roles of expanding residential development, increased outdoor recreation, and people's knowledge of, or tolerance for cougars (particularly recreationists and those living at the wildland-urban interface) also need considerable attention from researchers. Clear and strong inference is much more likely when studies are designed after generating specific and testable *a priori* hypotheses and appropriate controls and treatments are used to examine relationships among multiple biological and anthropogenic factors. Designs should explicitly account for potentially confounding elements when examining a single component. Because of the potential for inherent variation that could mask the effect of a treatment, multiple control-treatment study sites may be required. Collaboration among multiple states and organizations (i.e., state, federal, tribal or university) offers the most feasible approach for implementing replicate study sites without overwhelming the financial and staff resources of a single research entity. Each state would host a minimum of one control and treatment site with methodologies standardized and data analyzed as a single project. Standardizing data collection across jurisdictions to obtain a baseline measure of interactions prior to research implementation represents a necessary first step in the process.

Better quantifying the factors that affect risks of cougar-human interactions would be helpful to managers but understanding the most appropriate and effective responses to these interactions is an equally important need. The review revealed that the effects of many of the lethal and nonlethal strategies proposed to reduce risks of cougar interactions with people have not been adequately evaluated. Well-designed future research could reduce uncertainty regarding what strategies are most effective for reducing risk. Livestock and pet depredations represent most human-cougar interactions (Beausoleil et al. 2008), so research on nonlethal options should focus on the efficacy of tools and techniques to improve animal husbandry and reduce depredations. The efficacy of approaches this work could explore include, but are not limited to, audio and visual deterrents (e.g., human voices, motion-sensing lights), livestock guard dogs, low-cost boarding structures, and outreach programs to educate people about cougar ecology, behavior, and how to avoid conflicts. Work that includes comparing the economic viability of various tools would also be particularly useful.

Understanding the underlying mechanisms that increase or decrease risks of cougar-human interactions and what reduces conflict requires greater rigor than that embodied in scientific investigations on this topic to date. The rigor needed could be found in a research methodology that identifies an objective directly tied to a management need, develops falsifiable hypothesis *a priori*, and then applies a crossover or before/after control-intervention (i.e., BACI) design, preferably with multiple replicate study units. Application of a properly implemented control-treatment design is challenging on the large landscapes necessitated by cougar ecology but would be particularly useful for maximizing confidence in the validity of research findings.

When replicated treatment-control or BACI designs are not feasible, at a minimum, research results should be validated. When ecological models are developed from a dataset specific to a time and place of study, the model should be applied to a new, similar environment to see how well the model describes processes or outcomes in a new system.

Because humans are an unavoidable and integral component in wildland-urban systems and conflicts with cougars, directly engaging with members of the public will be essential for success. To ensure that people are successfully incorporated into research efforts, cougar researchers should actively collaborate with social scientists and experts on human behavior in all phases of study designs, implementation, and data analyses.

Cougar research is logistically challenging, expensive, and potentially contentious in any ecological setting, but even more so in wildland-urban environments. Consequently, policy makers need to provide sufficient resources, patience, and support to researchers to conduct long-term investigations (i.e., 8-10 years) within multiple study areas to ensure successful application of treatments and the acquisition of sufficient sample sizes. Rigorous study may require the manipulation of cougar or ungulate populations; this may be controversial and would require support from policy makers and stakeholders. Application of treatments in cougar research can be daunting, but it is not impossible. Evaluations of nonlethal methods and tools to reduce interactions are particularly well-suited for experimental manipulation (e.g., Ohrens et al. 2019) and long-term research projects completed in Montana (Robinson et al. 2014) and Colorado (Logan and Runge 2021) manipulated cougar populations via multi-year closures of cougar hunting seasons to investigate the effects of recreational harvest. Similarly, experimental manipulations have been used previously to explore questions about harvest composition (Anderson and Lindzey 2005) and predation effects on ungulate survival (Hurley et al. 2011).

The success of these studies clearly demonstrates the feasibility of experimental research designs in field settings. To date, similar experimental approaches have not been used to investigate links between specific management strategies and outcomes related to risks of interactions between cougars and people and represent the most promising path moving forward.

The dangers of using data post hoc to answer research questions has been highlighted through this through review of existing literature and research projects. It is obvious that a more rigorous approach to examine cougar-human interaction needs to be implemented to answer the most important questions. Data collection on interaction events must first be standardized across jurisdictions to provide a reliable base to measure interaction strength. Because of the issues discussed above with scale, closure, and sheer difficulty in obtaining sample sizes, large scale and long-term research should be designed to answer specific questions. The most feasible avenue to do this is a collaboration among several states, where a control/treatment design is proposed with each state collecting data in a few intensive study areas to be analyzed as a single project. A large scale design of this type would not suffer from the problems generally associated with the post hoc meta-analyses so typical in human/wildlife interactions and would also not overwhelm the financial and workforce of a single entity (State, Tribe, Federal Agency).

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Table 1. Summary of the studies reviewed for the 8 topical questions guiding of our review of cougar-human interaction literature.

Question 1: Do cougar removals through recreational hunting and/or agency conflict response affect the number of cougar-human interactions?

Authors	Year	Location	Source	Peer-reviewed
WA Dept. of Fish and Wildlife	2008	WA, USA	WDFW Agency Report	No
Kirsch et al.	2009	OR, USA	ODFW Agency Report	No
Peebles et al.	2013	WA, USA	PLOS ONE	Yes
Hiller et al.	2015	OR, USA	The Journal of Wildlife Management	Yes
Teichmann et al.	2016	BC, Canada	BMC Ecology	Yes
Laundré and Papouchis	2020	CA, USA	PLOS ONE	Yes
Dellinger et al.	2021	CA, USA	Human-Wildlife Interactions	Yes

Question 2: Does the size (N or density) or trajectory of the cougar population affect cougar-human interaction levels?

Authors	Year	Location	Source	Peer-reviewed
Aune	1991	MT, USA	Proc. of the 3rd Mountain Lion Workshop	No
Torres et al.	1996	CA, USA	Wildlife Society Bulletin	Yes
Lambert et al.	2006	WA, ID, USA; BC, CAN	The Journal of Wildlife Management	Yes
Hiller et al.	2015	OR, USA	The Journal of Wildlife Management	Yes
Kertson and Keren	2021	WA, USA	Journal of Mammalogy	Yes

Question 3: Does the abundance, diversity, and/or distribution of prey affect cougar-human interaction levels?

Authors	Year	Location	Source	Peer-reviewed
Polisar et al.	2003	Venezuela	Biological Conservation	Yes
Burgas et al.	2014	Costa Rica	Revista de Biologia Tropical	Yes

Question 4: Do preventative measures, such as nonlethal deterrence, quality husbandry, and outreach/education/information sharing affect the frequency of cougar interactions with people?

Authors	Year	Location	Source	Peer-reviewed
Gonzalez et al.	2012	Argentina	Human-Wildlife Interactions	Yes
Zarco-Gonzalez and Monroy-Vilchis	2014	Mexico	Animal Conservation	Yes
Guerisoli et al.	2017	Argentina	Royal Society Open Science	Yes
Alldredge et al.	2019	CO, USA	Ecology and Evolution	Yes
Ohrens et al.	2019	Chile	Frontiers in Ecology and the Environment	Yes

Question 5: Do landscape characteristics (e.g., residential development levels and/or patterns, habitat type, connectivity) affect cougar-human interaction levels?

Authors	Year	Location	Source	Peer-reviewed
Beier	1995	CA, US	The Journal of Wildlife Management	Yes
Sweanor et al.	2008	CA, USA	The Journal of Wildlife Management	Yes
Burdett et al.	2010	CA, USA	Ecosphere	Yes
Kertson et al.	2011	WA, USA	Ecological Applications	Yes
Wilmers et al.	2013	CA, USA	PLOS ONE	Yes
Zarco-Gonzalez et al.	2013	Mexico	Biological Conservation	Yes
Adams Knopff et al.	2014	AB, Canada	Biological Conservation	Yes
Benson et al.	2016	CA, USA	PLOS ONE	Yes
Jennings et al.	2016	CA, USA	The Journal of Wildlife Management	Yes
Montalvo et al.	2016	Costa Rica	Wildlife Biology in Practice	Yes
Moss et al.	2016	CO, USA	Journal of Applied Ecology	Yes
Smith et al.	2016	CA, USA	The Journal of Wildlife Management	Yes
Maletzke et al.	2017	WA, USA	Ecosphere	Yes
Blecha et al.	2018	CO, USA	Journal of Animal Ecology	Yes
Buderman et al.	2018	CO, USA	Movement Ecology	Yes
Alldredge et al.	2019	CO, USA	Ecology and Evolution	Yes
Guerisoli et al.	2019	Argentina	Journal of Mammalogy	Yes
Robins et al.	2019	WA, USA	Ecosphere	Yes
Smith et al.	2019	CA, USA	Landscape Ecology	Yes
Guerisoli et al.	2020	Range-wide	Mammal Review	Yes
Klees van Bommel et al.	2020	BC, Canada	Global Ecology and Conservation	Yes

Table 1 continued.

Authors	Year	Location	Source	Peer-reviewed
Question 5 continued:				
Riley et al.	2021	CA, USA	The Journal of Wildlife Management	Yes

Question 6: Does the number of people living, working, or recreating in cougar habitat affect the number of cougar-human interactions?

Authors	Year	Location	Source	Peer-reviewed
Sweanor et al.	2008	CA, USA	The Journal of Wildlife Management	Yes
Penteriani et al.	2016	North America	Scientific Reports	Yes

Question 7: Is the number of conflict reports/complaints correlated with actual frequency of conflicts (*i.e.*, is there published evidence that, with no change in real conflict, complaints may increase because of social tolerance or change in human perceptions [e.g., trail or doorbell camera use, news reports, etc.])?

Authors	Year	Location	Source	Peer-reviewed
No papers				

Question 8: Does the presence of other large carnivores, notably wolves, affect cougar proximity to, or the frequency of interactions with, people?

Authors	Year	Location	Source	Peer-reviewed
Shores	2020	WA, USA	University of Washington	No

Figure 1: Map of current and historic cougar (Puma concolor) range in North and South America. Map courtesy of the United States Fish and Wildlife Service (2020).

Appendix A: Prospective cougar-human interaction literature compiled from a combination of bibliographic lists of literature maintained by science team members, searchable research databases, and the literature cited in papers that were reviewed. Web of Science, Wildlife and Ecology Studies Worldwide, and Google Scholar research databases were accessed via the University of Washington library system and queried using the keywords, "Puma concolor", "cougar", "mountain lion", "puma", "interaction", "conflict", "depredation", "residential", "urban", and "wildland-urban interface" during the week of March 21, 2021.

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Appendix B: Literature Sorting Criteria - Criteria used to assign each of the 87 cougar ecology papers in our master literature list to one of four categories based on their direct relevance to factors that contribute to cougar proximity to, and interactions with, people in shared landscapes. Categorization was completed to facilitate additional review.

1) Do the objectives, hypotheses, methods, and results allow for direct inferences into the frequency/patterns of, or factors contributing to, cougar-human interactions?

   Yes: Include in Category 1 for potential full review.
   No: Continue to Criteria 2.

2) Do the objectives, hypotheses, methods, and results allow for direct inferences on factors that contribute to cougar use of residential areas or proximity to/overlap with people?

   Yes: Include in Category 1 for potential full review.
   No: Continue to Criteria 3.

3) Do the objectives, hypotheses, methods, and results allow for inferences on changes in population characteristics, ecological patterns, or behavior in response to anthropogenic factors (e.g., residential development, recreation) with potential implications for cougar-human interaction or proximity to people?

   Yes: Include in Category 2 for additional assessment.
   No: Continue to Criteria 4:

4) Do the objectives, hypotheses, methods, and results allow for inferences on the impacts of hunting on cougar population characteristics with potential inferences for cougar-human interaction or proximity to people?

Yes: Include in Category 3 for additional assessment.

No: Include in Category 4 – exclude from future consideration.

Additional selection criteria:

5) When source materials use all or some of the same data set (independent of direct rebuttal), preeminence for further review will default to the effort that uses a larger data set, quantitative methods, is peer-reviewed, and newer. If the alternative work contains only descriptive data, it will be assigned to Category 4 and not evaluated further.

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Dr. Kertson holds B.S., M.S., and Ph.D. degrees in Forest Resources (Wildlife Science) from the University of Washington. He is currently a Wildlife Research Scientist with the Washington Department of Fish and Wildlife focusing on large carnivores, particularly cougars. A principal focus of Dr. Kertson's research has been cougar wildland-urban ecology in western Washington and predator-prey dynamics in managed landscapes of eastern Washington. He previously studied predator-prey dynamics of wolves and elk in Idaho as a Wildlife Research Biologist for the Idaho Department of Fish and Game. Dr. Kertson is also an Affiliate Assistant Professor in the School of Environmental and Forest Sciences of the University of Washington working with graduate students on carnivore research projects throughout Washington.

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