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Please direct correspondence to:
Ange Darnell Baker
Editor-in-Chief
California Fish and Wildlife
Angela.Baker@wildlife.ca.gov

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Notes from the Editor

The third issue of 2021 is another of our special issues—this one focused on human-wildlife interactions. This issue contains a range of articles including interactions with terrestrial carnivores, mitigating hotspots of potential human-wildlife conflict, new ideas about how wildlife and people can coexist, and the human dimensions of conservation our state's wildlife. Victoria Monroe and Beth Pratt, who wrote our internal and external introductions to the issue, respectively, introduce and cover this important topic far better than I could, so I will let their introductions speak for themselves.

Speaking of Vicky, she was my co-editor for this issue, and I could not have done it without her. Not only was the issue completely her idea, she was integral in every part of its creation: soliciting articles, organizing the issue, acquiring photos, and editing the articles. Thank you Vicky!

What I would like to highlight in my notes this quarter is the loss of a very important member of the Journal's team, who is retiring (for the second time). Lorna Bernard was a television news reporter for 10 years prior to joining the Department in 1989 as a Public Information Officer. During her 20-year career with the Department, she served as a media liaison; oversaw public outreach programs including the endangered species "Tax Checkoff" program and the Keep Me Wild campaign to address wildlife/human interactions; and served as editor of Tracks magazine and the Department's Big Game Hunting Guide. She retired in 2010 but returned in 2015 to work as the Journal's layout technician.

I cannot say enough good things about Lorna. She was extremely welcoming to me when I came on board as editor, but even more importantly, she was exceptionally helpful and patient with me as I learned about my new role and how it worked. Lorna's attention to detail, patience, and work ethic made this journal better, and I do not know what I am going to do without her. Thank you, Lorna, and enjoy your (second) retirement!

Ange Darnell Baker, PhD
Editor-in-Chief
California Fish and Wildlife Journal

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Introduction

VICKY MONROE, *Conflict Programs Coordinator, Wildlife Health Laboratory, Wildlife Branch, California Department of Fish and Wildlife*

Human-Wildlife Conflict Transformation…Wildlife Health and Conservation in Action

Australia, California, Colorado, Washington D.C. metropolitan area…What do these places have in common? Though each is unique, the challenges – and opportunities – that arise specific to human-wildlife interactions are not. I speak from experience having lived, studied, and worked in each of these places. Though the wildlife may change – from Australian flying foxes (*Pteropus* spp.) to white-tail deer (*Odocoileus virginianus*), coyotes (*Canis latrans*) and black bears (*Ursus americanus*) - the types of concerns reported by people living alongside them remain remarkably consistent: Property damage, general nuisance, animal welfare, concern for public safety or human health…The list goes on. So, what does this observation tell us? We do not exist in isolation from other species. We are a PART of nature, not apart (separate) from nature. We interact within a shared environment, shared space, shared resources. Nature is all around us.

In California, what then is our vision for human-wildlife interactions, conflict mitigation, and coexistence with wildlife? Further, what are our responsibilities? As our perception of human responsibility and response to human-wildlife interactions has evolved, so too has the role of the California Department of Fish and Wildlife (CDFW). The CDFW serves as the lead state agency charged with helping to resolve human-wildlife conflict, public safety, and reported depredation. The CDFW also serves as the state agency contact for wildlife issues in all counties and communities; public education about wildlife conservation and public safety wildlife issues; participating in the development of strategies to monitor, assess, and manage wildlife disease; and responding to wildlife disease outbreaks (SWAP, 2015). People live increasingly in close contact with animals, both wild and domestic, as the human population expands along the wildland-urban interface and increases over time. This reality has led to increased human-wildlife interactions, and the potential for increased spread of endemic and emerging zoonotic diseases such as COVID-19.

On April 1, 2021, the CDFW Wildlife Investigations Laboratory officially became the CDFW Wildlife Health Laboratory (WHL). Using an "One Health" approach, interdisciplinary teams at the WHL, and their partners, investigate the complex interconnection between animals, people, and the environment. The CDFW recognizes the need for coordination and collaboration between diverse subject matter experts, including but not limited to veterinarians, researchers, geneticists, and social scientists. The WHL name change is one of many steps by the CDFW recognizing this approach as an increasingly critical strategy in California to "*achieve the best health outcomes for people, animals, and plants*" (Center for Disease Control and Prevention). Deeper understanding of human-wildlife interactions is central to this important work. Negative human-wildlife interactions can directly affect human and wildlife health and may result in loss of livelihood, reduced wellbeing, or in some instances, loss of life.

Human-wildlife conflict is contextual. One challenge – among many – when addressing this type of conflict is that human perception, attitudes, and tolerance towards wildlife fall along a diverse spectrum and can change over time. With this recognition, we must embrace the concept of biocultural diversity; that cultural and local community knowledge, identities, and traditions are interconnected with our natural resources. We cannot truly mitigate negative human-wildlife interactions without an awareness of the complex cultural, ecological, economic, and social factors that may inform how such interactions may be perceived and addressed.

Human-wildlife conflict has a cost. Negative interactions are often addressed via short-term mitigation measures (e.g., nonlethal deterrents, lethal control), but truly effective solutions require that we also understand and address the underlying causes (e.g., easy access to attractants). The solutions are not always permanent or simple. On a meta-level we must support a robust policy, statutory and regulatory framework that recognizes the interconnection between humans, wildlife, and the environment. California's 30×30 initiative (Executive Order N-82-20) is one such example. On a granular level, we must actively engage and work together with agency partners, local communities, and stakeholders to develop and support resources that encourage safe coexistence. We cannot avoid all undesirable human-wildlife interactions. However, we can create a framework whereby both human and wildlife needs are met.

Safe coexistence is possible. It can yield tangible, measurable benefits (e.g., ecological, economic, social, physical/emotional wellbeing). For those who question coexistence as an option - or solution - it is important to clarify its meaning. Coexistence is a commitment to understanding and valuing our connection with wildlife. What safe coexistence looks like in one community, may look very different in another. Coexistence requires an integrated strategy based on public education, outreach, (human) behavioral change, and proactive mitigation measures. There is power in recognizing human responsibility and our ability to make changes. Proactive measures may include nonlethal (e.g., deterrent devices, permanent exclusion) and lethal methods (e.g., targeted removal of offending animal, ethical hunting), depending on species, conflict type, and other factors. Coexistence is *not* the absence of lethal measures as an option. Practitioners, resource managers, and property owners must have knowledge of, and access to, diverse tools for effective conflict mitigation.

- We must adapt, evolve, and wholly embrace our role in the process.
- We must integrate and value indigenous knowledge, with institutional knowledge.
- We must recognize the barriers to effective mitigation– such as economic, cultural, or other factors that may limit people's options or access.
- We must shape and share messages, that are accessible, and resonate with local communities and the diverse publics about human-wildlife interactions.

Committing to effective, long-term approaches that support safe coexistence is, in effect, a commitment to wildlife conservation and biodiversity resiliency. We are called now to adapt how we recognize and approach the interconnectedness that exists between people, wildlife, and the environment. This Special Issue has never been more salient or timely in advancing the discussion and understanding of human-wildlife interactions. We will explore various interconnected themes across each section: Terrestrial Predator Interactions, Conflicts & Adaptive Management, Coexistence & Conservation, and the Human Dimensions of Wildlife Conservation. We hope you recognize the myriad factors that shape human-wildlife interactions in California, and value the diverse expertise and lived experiences of those contributing to this issue.

Introduction—continued

BETH PRATT, *California Regional Executive Director, National Wildlife Federation*

What We Talk About When We Talk About Coexistence

If a perfect poster-animal for human-wildlife coexistence ever existed, it's P-22, the famous mountain lion living under the Hollywood sign. Often called the 'Brad Pitt of the cougar world'—they are both ruggedly handsome, beloved around the globe, and challenged with their dating lives—P-22 made a miraculous journey and crossed two of the busiest freeways in the country to make a home in Griffith Park, where he has roamed since 2012, coexisting peacefully with the over 10 million visitors a year, and remaining largely unseen as befitting his species nickname, "ghost cat." Occasionally he makes an appearance on the Ring doorbell cam of one of the homes surrounding Griffith Park—the footage from these encounters is widely shared on social media with the same excited and reverent tones a devoted fan would use upon meeting Mr. Pitt.

This plight of this celebrity cat has been featured in *The New Yorker, Men's Journal, Teen Vogue, NPR, 60 Minutes, The Guardian* (with my favorite headline, "Can there be a Hollywood Ending for the 'Brad Pitt' of mountain lions?") and many other news outlets around the globe—he's racked up over a billion media hits worldwide. P-22 has a museum exhibit, a clothing line, and a hip-hop song. The City of Los Angeles declared an official day in his honor, October 22, and over 8,000 people attend the annual P-22 Day Festival. P-22 possesses a Facebook page with over 16,000 followers, and even has a celebrity posse that has posed for a photo with him (well, his likeness in a life-size cardboard cutout) that includes James Cameron, Rainn Wilson, Sean Penn, and Shania Twain. Governor Gavin Newsom even tweeted out a selfie of himself with the cutout, saying: "P-22 will always have my heart ."

The only thing he doesn't have is a girlfriend. He's the only cougar in Griffith Park, trapped by those same freeways he crossed. Tears at the heartstrings, right? Fans have even set up fake Tinder accounts for him in the quest for a love match.

I know at this point many reading this article are cringing or shaking their head, decrying anthropomorphism, this departure from science and research, and questioning my heresy.

(A reference in my defense: An article in *The New Yorker* profiling Rachel Carson related how she read Beatrix Potter and *The Wind and The Willows* in her childhood. Those early anthropomorphism -laden books didn't seem to detract from her impact as a biologist.)

In response, first, I am a scientist. Second, I have the receipts. Because of a lonely, dateless mountain lion, the second largest city in the country has shown an unprecedented acceptance to living among native wildlife. And people have donated over $72 million and counting to build the world's largest wildlife crossing because the public wants to prevent the extinction of the Santa Monica Mountains cougars and continue to live alongside *Puma concolor* in the most densely populated region in the United States.

For all this fun and fame surrounding P-22, and beyond the "Who is Hotter: Brad Pitt or P-22?" contests on his Facebook page, this approach to coexistence is creating a new value system toward wildlife. This is California's cult of celebrity applied to the animal world, and put to good use, for these are reality shows worth watching because they can have significant impacts on conservation.

Author Jon Mooallem made this point full force in his TED talk "The strange story of the teddy bear and what it reveals." He relayed how President Theodore Roosevelt in 1902, by sparing the life of a frightened black bear, inspired the Teddy bear, and changed the attitude across the country toward bears from that of terrifying monsters to an animal that children cuddled at bedtime. As Jon observes in his talk: *"In a world of conservation reliance, those stories have very real consequences, because now, how we feel about an animal affects its survival more than anything that you read about in ecology textbooks. Storytelling matters now. Emotion matters. Our imagination has become an ecological force."*

The P-22 story has inspired a new coexistence paradigm. Further evidence: When our boy also infamously made a snack of a koala in the Los Angeles Zoo, what happened? The Zoo apologized for their fences being too short, and the public rallied to his defense with—'he just thought it a strange raccoon' excuse. As the New York Times reported, *"But far from prompting an outcry about public safety, the koala's death has revealed a city at ease with wildlife in its midst, even potentially dangerous specimens. Opinion pieces opposing any effort to remove P-22 have appeared in local newspapers."*

For those who think this approach only works on charismatic mega-fauna, I offer the 180 degree change of attitudes about another much-feared creature most people used to flee from in terror: bees. I grew up in the 1970's when movies like *The Swarm* gave me nightmares. In today's world, you see tweets like this one from @tracey_thorn: "I remember when I used to see a bee and go YIKES a bee. And now I'm all "wow a bee, hi! You okay there? Need anything? Can I get you a drink? A cushion? Want to borrow the car?"

Science is important. Science tells us how to coexist and we need to lead with the science for solutions. But it's the stories, the inspiration, the capturing of the imagination that will ensure people embrace the coexistence ethic, learn the science and take action. So, the next time you host a workshop, present research, create a pamphlet, or post rules asking people to coexist, take a deep breath, get over that aversion to "anthropomorphizing" and also remember to tell a story. Help people meaningfully connect to the wild world and build a lasting relationship with wildlife, and coexistence (and a reduction in conflict) will follow.

Terrestrial Predator Interactions

Terrestrial Predator Interactions

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1. Young coyote (*Canis latrans*) carrying a snake in its mouth. Photo Credit: Sheryl Hester, Photographer.
2. Livestock guardian dog watching over lambing ewes (Case Study 2). Photo Credit: Dan Macon, University of California Cooperative Extension, Division of Agriculture and Natural Resources.
3. Mountain lion (*Puma concolor*), P-35, feeding on a mule deer carcass in the Santa Monica Mountains, California. Photo Credit: National Park Service.
4. Bobcat (*Lynx rufus*) walking at night along trail overlooking Los Angeles. Photo Credit: Johanna Turner, Cougar Conservancy.
5. Litter of mountain lion kittens held by researchers in the Santa Monica Mountains, California. Photo Credit: National Park Service.
6. Gray wolves (*Canis lupus*) near Sierra Valley, California. Credit: USDA-Wildlife Services.

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RESEARCH NOTE

Summer diet of California's recolonizing gray wolves

JUSTIN A. DELLINGER[1*], KENT LAUDON[2], AND PETER FIGURA[2]

[1] *California Department of Fish and Wildlife, Wildlife Investigations Lab, 1701 Nimbus Road, Rancho Cordova, CA 95670, USA*

[2] *California Department of Fish and Wildlife, Northern Region, 601 Locust Street, Redding, CA 96001, USA*

**Corresponding Author: justin.dellinger@wildlife.ca.gov*

Key words: biomass ingested, cattle, *Canis lupus*, black-tailed deer, percent frequency of occurrence

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After an estimated 87-year absence (circa 1924–2011), gray wolves (*Canis lupus*) have begun to recolonize California (Grinnell et al. 1937; Kovacs et al. 2016). Prior to European colonization, gray wolves are thought to have subsisted on native prey including mule deer (*Odocoileus hemionus*) and elk (*Cervus elaphus*; Grinnell et al. 1937). Due to concerns about the potential effects of gray wolves on both native ungulates and livestock, our objective was to assess the diet of California gray wolves (CDFW; Kovacs et al. 2016).

Gray wolves generally use prey species in accordance with their availability (Nowak et al. 2011; Meriggi et al. 2015). For example, native ungulates are more abundant in North America than in Europe and Asia, and gray wolves in North America rely primarily on native ungulates while gray wolves in Europe and Asia rely more on domestic animals (Torres et al. 2015; Newsome et al. 2016; Janeiro-Otero et al. 2020). As there are lower densities of native ungulates in California than other areas of North America where gray wolves exist (CDFW 2018; Furnas et al. 2018), gray wolves in California may use relatively more alternative prey such as beavers (*Castor canadensis*), rabbits (*Sylvilagus* spp. and *Lepus* spp.), and livestock. While it will require additional work to thoroughly describe the diet of wolves in California, our approach and analyses to date offer a framework for future study and helping wildlife managers better understand aspects (e.g., diet composition and scavenging behavior) of wolf diet in California.

The Lassen pack, located east of Lassen Peak and Lake Almanor, roams over parts of Lassen and Plumas Counties and was first documented in 2016. The pack has produced litters each year from 2017–2020. We used abandoned den and rendezvous sites of the Lassen pack to collect adult-sized wolf scats to determine the diet of the pack. We also collected adult sized wolf scats opportunistically along dirt roads, game trails, and feeding sites. Because the Lassen pack has mostly distinct summer and winter ranges, we assumed scats collected opportunistically in the summer home range were deposited during summer months. Scats were collected in 2017 (May–October), 2018 (June–October), and 2019 (April–July); the majority (89%) of overall scats represent scats deposited April–July for all years.

A subset (47%) of collected scats were genetically verified (Frantzen et al. 1998; Adams et al. 2007) as originating from *Canis lupus;* others were identified as adult wolf based on size (≥29 mm diameter for adult scat; Weaver and Fritts 1979) or by location at a den/rendezvous site. All scats >29 mm were genetically verified as wolf scats, supporting our use of scat diameter alone to identify adult wolf scat (e.g., Dellinger et al. 2011b).

Scats were individually washed to separate hair and bone fragments. Those contents were identified by comparing them to reference materials (e.g., CDFW collections; Moore et al. 1974) and assigned to one of three categories: black-tailed deer (*Odocoileus hemionus columbianus*), cattle (*Bos taurus*), and small mammals (e.g., raccoon [*Procyon lotor*], rabbit, beaver, and ground squirrel [*Spermophilus* spp.]). We used two metrics to rank and determine overall and annual (i.e., each summer during the three years of data collection) percent contribution of food items in scats. One metric was percent frequency of occurrence (PFO; Ciucci et al. 1996; Steenweg et al. 2015), where the frequency with which each food item occurs in individual scats is expressed as a percentage of the total number of occurrences of all food items. The second metric was biomass ingested (BI; Weaver 1993; Dellinger et al. 2011a), which is an estimate of prey biomass consumed per collectable scat produced. Each method is recognized as having biases and using both may provide a better description of diet than using only one method (Ciucci et al. 1996; Dellinger et al. 2011a). PFO can over represent smaller prey items in the diet (Klare et al. 2011) but, unlike BI, PFO does not rely on assumptions of live weight of each species consumed. Items that were <1% of a scat were ignored (Gable et al. 2017). For BI we set live weight of each species as: black-tailed deer – 45 kg (average weight of a black-tailed deer across all sex and age classes per Walmo 1981 when weighted by age and sex demographic ratios per Furnas et al. 2018), cattle – 272 kg, small mammals – 8 kg (Jameson, Jr. and Peeters 2004). Live weight for cattle was derived from average estimated live weight of calves, yearlings, and cows present in the Lassen packs home range (CDFW unpublished data). Average live weight for small mammals was determined by considering frequency of each small mammal species (beaver, raccoon, rabbit, and ground squirrel) in the diet as well as typical live weight of each (Jameson, Jr. and Peters 2004).

We collected 92 adult scats from the Lassen pack (13, 45, and 34 scats in summer and fall 2017, 2018, and 2019, respectively). PFO for black-tailed deer, cattle, and small mammals for scats pooled across years was 51%, 32%, and 17%, respectively. BI for scats pooled across years indicated black-tailed deer, cattle, and small mammals made up 29%, 59%, and 12%, respectively, of the Lassen pack diet (Table 1). The divergent estimates for these two primary items are expected based on the differences in how the two metrics are derived, and since neither is definitively correct, these results demonstrate the value of using multiple metrics to assess diet. Though the two metrics indicate differential, and almost opposite, contribution of black-tailed deer and cattle to the Lassen pack diet during summer, together both indicate black-tailed deer and cattle are key food sources. We did not find any vegetation, fruit, or anthropogenic material in scats. Although elk comprise an important part of the diet of many packs in the western United States (Newsome et al. 2016), they are uncommon transients in the Lassen pack territory (CDFW, unpublished data) and were not detected in scats. However, population growth and expansion of the elk population in northern California could change prevalence of elk in the Lassen pack diet (CDFW 2018).

Given that black-tailed deer and cattle made up most of the overall and annual summer diet of the Lassen pack, we attempted to discern if the pack was utilizing these food

Table 1. Overall and annual diet composition of the Lassen wolf pack in California, 2017-2019, according to adult scat analyzed using two diet metrics (percent frequency of occurrence and estimated biomass ingested). Amounts of each prey item contributing to diet composition are represented as percentages of total diet composition.

	Percent Frequency of Occurrence			Biomass Ingested (estimated)		
	Deer	Cattle	Small Mammals	Deer	Cattle	Small Mammals
2017	51	41	8	26	67	7
2018	55	31	14	31	58	11
2019	47	30	23	27	56	17
Combined Years	51	32	17	29	59	12

items in proportion to their availability (Meriggi et al. 1996, 2015; Milanesi et al. 2012). We estimated availability of each food item in terms of both the number of individuals and the amount of biomass present within the pack's summer range. We first estimated the summer range (April–September) as ~284 km^2 using a 95% adaptive local convex hull (a-LoCoH; Getz et al. 2007) derived from 1,920 satellite-collar locations from one radio-collared member of the pack. Based on an estimate of 5.2 deer per km^2 for a study area that overlapped significantly with the Lassen pack's summer range (Furnas et al. 2018), we estimated ~1,477 black-tailed deer available to the pack. That estimate included both sexes and all age classes of deer with a fawn:doe:buck ratio of 0.67:1.0:0.37. Based on a weighted average of 20 kg for fawns (average for the entire summer), 54 kg for does, and 65 kg for bucks (Walmo 1981), we estimated deer biomass to be 233 kg/$km^{2,}$ or 66,172 kg within the summer range.

We used United States Forest Service (USFS) and private lands stocking data to estimate cattle numbers and biomass in the summer territory. For USFS allotments, we determined how many cow-calf pairs were turned out in 2017, 2018, and 2019. We then calculated area of each allotment within the pack's home range, multiplied the clipped area of each allotment by the average annual cattle density for that allotment and summed the results across all allotments within the range, which provided an estimate of ~644 cow-calf pairs on federal allotments within the Lassen pack's summer range during the study period. We then queried livestock producers with range cattle on private lands within the territory to determine the number of cow-calf pairs on those lands that did not also range onto USFS allotments (660 pairs). We summed those "private-only" cattle with the cattle on USFS allotments to derive an estimate of 1,304 cow-calf pairs, or 2,608 individual cattle, within the estimated summer range. This total number is approximately 9.18 cattle/km^2. Using an average weight of 272 kg for all cattle available, and multiplying by the density of available cattle in the study area, we estimated 2,498 kg/$km^2$of cattle biomass available to the Lassen pack during summer. This equated to an overall biomass of 709,432 kg of cattle within the Lassen summer range.

We then compared the overall number of scats containing each item as estimated from PFO to the estimated number of individuals available ((Meriggi et al. 1996; Milanesi et al. 2012). We also compared the overall estimates for BI for both species to the derived biomass of each species available (Meriggi et al. 2015). A food item was deemed used more than expected if the 95% confidence intervals for proportion of that item in the diet were greater than the proportion of that item available (Manly et al. 2002). Conversely, a food item was deemed used less than expected if the 95% confidence intervals for proportion of that item in the diet were less than the proportion of that item available (Manly et al. 2002).

Based on the proportion of individuals available (36% and 64% deer and cattle, respectively, or 1,477 deer and 2,608 cattle) and proportion of scat composed of black-tailed deer (51%) and cattle (32%) as determined from overall PFO, we determined that in the summer the Lassen pack was utilizing black-tailed deer more than expected based on availability and cattle less than expected (Table 2). Based on the proportion of biomass available (9% and 91% deer and cattle, respectively, or 66,172 kg deer and 709,432 kg cattle) and proportion of diet composed of black-tailed deer (29%) and cattle (59%) as determined from overall BI, we also determined the Lassen pack was using black-tailed deer more than expected and cattle less than expected in summer. Although both the raw PFO and BI metrics for deer and cattle varied, our estimates of deer and cattle utilization relative to availability were consistent for both metrics. Janiero-Otero et al. (2020) also found that across their biogeographic range, wolves generally used wild prey more than livestock when the relative abundance of each was taken into account.

Table 2. Estimation of utilization by adult members of Lassen pack for two primary prey items, black-tailed deer and cattle, using number of individuals and biomass (kg) available, respectively. Derivations of numbers of individuals and biomass available are detailed within the text. Proportions of each prey item used were calculated from the overall percentages displayed in Table 1. Use of a prey item more than expected is indicated if the 95% confidence interval for the corresponding proportion of that prey item in the diet is above the proportion available. Use of a prey item less than expected is indicated if the 95% confidence interval for the corresponding proportion of that prey item in the diet is below the proportion available.

	Percent Frequency of Occurrence		Biomass Ingested (estimated)	
	Deer	Cattle	Deer	Cattle
Available (# and biomass)	1,477	2.608	66,172	709,432
Proportion Available	0.36	0.64	0.09	0.91
Proportion Used (95% CI)	0.51(0.39-0.63)	0.32(0.21-0.43)	0.29(0.20-0.39)	0.59(0.48-0.69)
Use Ratios	1.41	0.50	3.41	0.64
Use compared to expected	More	Less	More	Less

Because our data is only derived from a single California wolf pack, our results should be viewed as preliminary. The tendencies of the individual wolves in the pack or the physiography of the pack's territory may influence wolf diet composition. For example, the Lassen pack's den sites and most of their rendezvous sites have been close to large meadow complexes where grazing cattle are aggregated from May through October each year. Scats collected from those sites might be expected to contain an increased frequency of cattle remains than scats collected in other parts of the pack's summer range. Additional study limitations were the lack of systematic scat collection throughout the study period, despite a food base that varies temporally over the period (e.g., birth of deer fawns peaking in early to mid-June, turnout of cattle in mid-June, etc.). Scats were collected opportunistically and not in any temporally (e.g., every week) or spatially (e.g., routes) standardized way. Additionally, we pooled samples collected at den and rendezvous sites with samples from roads, trails, and feeding sites. While some studies have found no differences in the contents of scats collected at different locations (Gable et al. 2017), others have found differences in contents of wolf scats collected along roads and those collected at den and rendezvous

sites (Steenweg et al. 2015). It should be noted that contents of scats collected at feeding sites did not always match the species fed upon at the same site. Nonetheless, collection of 10–20 adult wolf scats per month from homesites or opportunistically can provide a general understanding of the annual diet of a given wolf pack (Dellinger et al. 2011a; Gable et al. 2017). We are currently employing spatially and temporally standardized scat collection methods (i.e., regularly surveyed routes bisecting the pack's summer range) and accounting for where scats are collected (i.e., homesite, road, or feeding site) to help address these limitations in the future.

We acknowledge that quantifying available number and biomass of black-tailed deer and cattle on the landscape is an imprecise exercise. Our estimate of black-tailed deer live weights was taken from the literature and may be greater than the typical live weights of deer living in the Lassen pack home range (CDFW, unpublished data). Our estimates of black-tailed deer biomass available on the landscape groups yearlings with adult deer which also likely contributes to overestimating deer biomass on the landscape. Further, estimating cattle live weight was difficult due to variation in calving cycles between local livestock operations. For example, calves born in the fall of a previous year would weigh more than calves born in spring of the following year. However, using lower black-tailed deer live weights and accounting for larger calves born in the fall would only increase the already large difference in estimated biomass of black-tailed deer and cattle available.

Our analysis does not indicate the proportion of the pack's diet that is scavenged versus killed. Although the Lassen pack sometimes kills and consumes cattle, pack members also regularly visit the carcasses of cattle that have died of natural (i.e., non-depredation) causes (CDFW, unpublished data). Petroelje et al. (2019) found that most cattle in the diet of wolves in Michigan, USA were from scavenging. When possible, future dietary studies in California should therefore use techniques that allow estimation of the proportion of killed vs. scavenged food items (e.g., satellite collars with many fixes per day, camera-collars, etc.). Further, understanding the role of smaller native animals in Californian gray wolf diets will also be important. Small native prey like beavers, lagomorphs, microtine rodents, birds, fish and, on occasion, other carnivores, can supplement wolf diets during ungulate shortages (Newsome et al. 2016)

Our assessment of diet was limited to samples gathered from the Lassen pack's summer range. The winter diet of the pack may differ from its summer diet, as it shifts it range to lower elevations in the winter (Morehouse and Boyce 2011). Deer and cattle are both present on the pack's winter range, but relative to summer range, cattle are fewer in number, confined to smaller pastures, and closer to human dwellings. Given that livestock depredation has thus far been less common in winter than summer (CDFW, unpublished data), it is possible that the Lassen pack may consume less cattle in winter relative to summer. To address this potential difference, we intend to expand upon our current efforts and study diet year-round.

Several recent assessments suggest potentially suitable gray wolf habitat is widespread in northern California and the Sierra Nevada where the potential for wolf-livestock conflict is high in many areas due to the extensive presence of livestock (Kovacs et al. 2016; Nickel and Walther 2019). Though our initial work suggests that wolves in California use native ungulates as, or more than expected based on availability, cattle depredations are likely to continue to occur given the abundance of cattle on the landscape (Janeiro-Otero et al. 2020). However, as this study demonstrates the importance of deer in the Lassen pack's diet, increases in deer populations may potentially reduce livestock predation.

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FULL RESEARCH ARTICLE

Conflict, coexistence, or both? Cougar habitat selection, prey composition, and mortality in a multiple-use landscape

DAVID C. STONER,[1*] MARK A. DITMER[2], DUSTIN L. MITCHELL[1,3], JULIE K. YOUNG[1,4], AND MICHAEL L. WOLFE[1†]

[1] *Department of Wildland Resources, Utah State University, 5230 Old Main Hill, Logan, UT 84322-5230, USA*

[2] *USDA Forest Service, Rocky Mountain Research Station, 324 25th Street, Ogden, UT 84401, USA*

[3] *Utah Division of Wildlife Resources, 319 N Carbonville Rd, Suite A, Price, UT 84501, USA*

[4] *USDA/APHIS/WS National Wildlife Research Center, Millville, UT 84326, USA*

[†] *Professor Emeritus*

**Corresponding Author: david.stoner@usu.edu*

Western North America is experiencing remarkable human population growth and land-use change. Irrigation and associated cultivation have led to colonization of urban-wildland interface (UWI) environments by mule deer (*Odocoileus hemionus*), and consequently, cougars (*Puma concolor*). In the wake of these changes, human-wildlife conflicts have increased in tandem with questions about long-term species conservation. To address these concerns, we fit 79 cougars with radio-telemetry collars in the Oquirrh Mountains near Salt Lake City, Utah (2002–2010). Our goal was to evaluate variation in cougar habitat selection, diet, and cause-specific mortality in a landscape dominated by urban, military, and industrial activities. We used radio-telemetry data in concert with Resource Selection Functions to address three hypotheses: (1) that cougars would select wildland over UWI land-uses; (2) prey composition would reflect differences in land-use; and (3) mortality would be predominantly human-caused. Cougars largely selected wildland habitats associated with seasonal mule deer presence, but contrary to expectation, they also selected habitats closer to urban and mined areas. Prey composition in the UWI did not differ from wildland habitats. Domestic ungulates represented only 2% of 540 recovered prey items and were found primarily in wildlands. Native ungulates comprised > 90% of the total kill, irrespective of season or land-use, suggesting that use of UWI habitats was linked to mule deer presence. Cougar mortality was disproportionately due to natural causes in wildlands, but individuals that died of human causes in UWI habitats

were more likely to be inexperienced hunters, supporting young kittens, or compromised by physical handicaps. In general, presence of mule deer was the key predictor of cougar habitat use, even in this highly disturbed, anthropogenically altered landscape. As such, management designed to reduce conflict and ensure conservation will need to focus on urban deer, land-use planning, and targeted education campaigns to reduce food subsidies.

Key words: GPS, habitat selection, human-wildlife conflict, mountain lion, predation, *Puma concolor*, urban deer, urban-wildland-interface, Utah, wildlife management

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Land-use change, water appropriation, and species loss are hallmarks of the Anthropocene (Ellis 2015). Human beings have harnessed and redistributed ecosystem productivity to meet rising demands for food production, minerals, housing, and transportation (Imhoff et al. 2004). These patterns have led to the loss, isolation, and fragmentation of wildlife habitats (Radeloff et al. 2005; Leu et al. 2008). Of these, the redistribution of water has had particularly profound effects in the western United States. The proliferation of irrigation agriculture and ornamental landscaping has decoupled primary productivity from climate signals, thereby turning agricultural and urban areas into highly productive habitats in otherwise arid environments (Buyantuyev and Wu 2012; Li et al. 2017). Altered disturbance regimes such as wildfire have further compounded these trends (Roerick et al. 2019). These land-use changes have impacted biodiversity in two important ways. First, through the extirpation of rare or wide-ranging species, and second, by opening opportunities for habitat generalists (McCullough et al. 1997; Baruch-Mordo et al. 2014; Hansen et al. 2020). Both phenomena have led to increased social concerns over species conservation and human-wildlife conflicts (Rodgers and Pienaar 2017).

Ungulates may be attracted to anthropogenic environments seeking forage (Polfus and Krausman 2012; Longshore et al. 2016) or to avoid the energetic cost of navigating deep snow (Parker et al. 1984; Olson et al. 2015). The predictable presence of highly palatable/nutritious forage can lead to the loss of migratory behavior (McClure et al. 2005; Barker et al. 2019) and colonization of anthropogenic landscapes (Robb et al. 2019). Under these conditions, management efforts have focused on mitigating disease transmission (Farnsworth et al. 2005), wildlife-vehicle collisions (Bissonette et al. 2008), and crop depredation (Anderson et al. 2012). However, there is a growing concern among the public and wildlife managers that the seasonal or annual presence of mule deer (*Odocoileus hemionus*) and other ungulates in urban areas has the potential to attract large carnivores with implications for human safety and domestic animal depredations.

Human activity presents carnivores with both costs and opportunities. The presence of garbage, big game gut piles, or roadkill can serve as food resources, inadvertently creating highly predictable subsidies to ecosystems of low or variable productivity (Ruth et al. 2003; Baruch-Mordo et al. 2014; Coon et al. 2019). Human altered landscapes offer an abundance of exotic and naïve prey such as domestic animals (pets, livestock). Additionally, these environments attract small mammals that exploit anthropogenic food sources, supporting larger populations that in turn attract mesocarnivores (e.g. racoons, coyotes, skunks, and possums; Hansen et al. 2020). That said, human caused mortality is almost universally cited in studies of carnivores, even in remote or nominally protected areas (Woodroffe and Ginsburg 1998;

Packer et al. 2009), suggesting that exploitation of these resources carries substantial risks. Moreover, individual tolerance of human activities varies within populations, and among species and (Myers and Young 2018).

Cougars (*Puma concolor*) are still widely extant across much of western North America, with their occurrence in a given community predicated on the presence of ungulate prey and adequate stalking cover (Pierce and Bleich 2003). The adaptability and ecological success of this predator is evidenced by its resilience following the Pleistocene extinctions (Culver et al. 2000), wide latitudinal distribution, and current expansions into the boreal forests (Jung and Merchant 2005), agricultural lands (Thompson et al. 2009; Gigliotti et al. 2019), deserts (Choate et al. 2018; Dellinger et al. 2018), the eastern USA (LaRue et al. 2012), and urban-wildland interface ecosystems (Coon et al. 2019). However, as large-bodied, obligate carnivores, cougars have extensive spatial requirements and occur at low densities (Stoner et al. 2018), making them vulnerable to hunting (Stoner et al. 2006) and habitat fragmentation (Beier 1995). Indeed, relict populations isolated by urban sprawl are those that best exemplify the social dilemma between species conservation and conflict mitigation (Rodgers and Pienaar 2017).

The public attention to wildlife management responses to human safety concerns has led to investigations of cougar habitat use, behavior, and predation in non-wilderness settings (e.g. Kertson et al. 2011; Wilmers et al. 2013; Alldredge et al. 2019) and reactions to anthropogenic landscapes (Knopff et al. 2014; Ditmer et al. 2020). Debate exists on the sensitivity of cougars to non-lethal anthropogenic influences. Preliminary results have demonstrated cougar use of habitats adjacent to major metropolitan areas while exhibiting a general aversion to human activities (Beier et al. 2010). Murphy et al. (1999) hypothesized that cougars may avoid disturbances such as mining, logging, or recreation if these activities are associated with a threatening human presence. The authors conceded, that in the absence of strong negative consequences, cougars may continue to frequent areas of predictable human activity. Ripple and Beschta (2006) further postulated that the mere presence of humans in large numbers, such as tourists in national parks, can render otherwise high-quality habitat unsuitable. Although not supported by field data, these arguments match the general hypothesis of cougar as a wildland obligate. In contrast, reviews by Beier et al. (2010) and Sweanor and Logan (2010), and a growing body of original research (Alldredge et al. 2019; Knopf et al. 2014) present a more nuanced view, suggesting that in near-urban populations, cougars exhibit individualistic responses to human activities even in the face of substantial human-caused mortality.

Redistribution of limiting resources in the wake of urban expansion has resulted in colonization of anthropogenic landscapes by mule deer and other ungulates (Polfus and Krausman 2012), accompanied by increases in cougar depredation of domestic animals, attacks on humans, and errant cougars in highly populated areas (Torres et al. 1996; Mattson et al. 2011). These phenomena have raised questions about cougar behavior in human-altered landscapes, and more importantly, how to manage human-wildlife conflict, while conserving populations impacted by anthropogenic activities. Our goal was to evaluate variation in cougar habitat selection, diet, and mortality with respect to land-use types. To achieve this, we addressed three working hypotheses: (1) cougars would select for wildlands over anthropogenic land-uses; (2) prey composition would reflect land-use; and (3) mortality would be predominantly human-caused. To test these hypotheses, we compiled data on cougar movements, predation events, and cause-specific mortality across a landscape disturbed by a range of anthropogenic activities.

METHODS

Study Area

The Oquirrh-Traverse Mountains form a boot-shaped complex (hereafter the Oquirrhs) in north-central Utah (40.5° N, 112.2° W) on the eastern edge of the Great Basin (Fig. 1). The ecoregion is defined by basin and range topography, in which mountains form islands of high productivity relative to the surrounding desert basins, and thus constitute the majority of cougar habitat in an area otherwise defined by aridity. The Oquirrhs measure > 950 km², but fieldwork was focused on 500 km² encompassing properties owned and managed by the Kennecott Utah Copper Corporation (Rio Tinto Kennecott) and the Utah Army National Guard (Camp Williams). The site is bounded on the north by the Great Salt Lake and on the east by the Salt Lake Valley, which is home to approximately 40% of the state's population. Approximately 45% of the range is privately held or closed to the public (mining, military, aerospace). The remaining land is under the jurisdiction of the Bureau of Land Management (BLM). We selected this site because of its proximity to the greater Wasatch Front metropolitan area, the diverse suite of human activities and associated land uses, and the lack of public access.

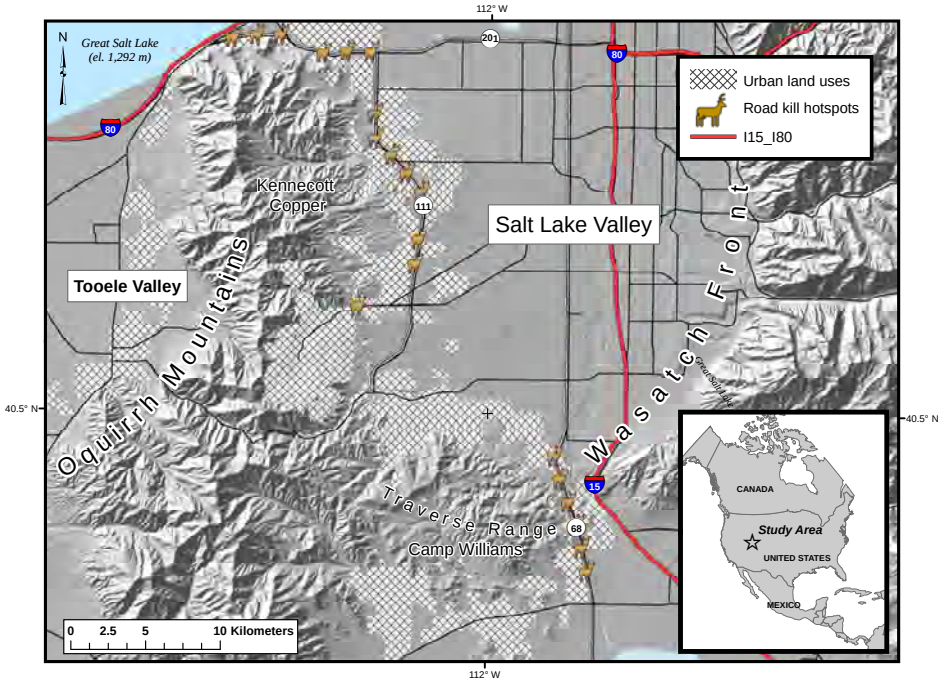

Figure 1. Cougar demography, behavior, and habitat use were studied in the Oquirrh Mountains, Utah from 1997–2010. The site was selected because of its proximity to the Salt Lake City metro area and lack of public access. The site was closed to hunting, but impacted by a wide range of human activities and land uses, including mining, military operations, residential development, and agriculture. The study was initiated in 1997, and GPS technology was introduced in 2002. Hatched area represents the urban-wildland interface (UWI).

Elevation ranges from 1,292 m to 3,200 m, and is correlated with variation in moisture, vegetation, and faunal diversity. Annual precipitation ranges from 30–40 cm in the Salt Lake and Tooele valleys to 100–130 cm on the highest ridges and peaks. Precipitation is bimodal, with most falling as snow from December–April, followed by a sporadic late summer monsoon. Mean monthly temperatures range from –2.4°C in January to 22.2°C in July (Banner et al. 2009). This climatic regimen supports a variety of plant communities. Foothills are dominated by Gambel oak (*Quercus gambelii*), sagebrush (*Artemisia tridentata*), and Utah juniper (*Juniperus osteosperma*). Canyon maple (*Acer grandidentatum*) is prevalent in riparian zones at low elevations and across broader areas above 1,800 m. Mountain mahogany (*Cercocarpus spp.*) is common on ridges and well-drained soils. North facing slopes above 2,200 m support localized aspen (*Populus tremuloides*) and Douglas fir (*Pseudotsuga menziesii*) forests. Mule deer and elk (*Cervus canadensis*) are the primary ungulate prey species occupying the site, but a small number of pronghorn antelope (*Antilocapra americana*) and feral horses (*Equus caballus*) occur on the periphery of the site. Free-ranging livestock, including cattle (*Bos taurus*), sheep (*Ovis aries*), goats (*Capra hircus*), and domestic horses are present from May–December. Potential competitors include coyotes (*Canis latrans*) and bobcats (*Lynx rufus*). Historically bighorn sheep (*Ovis canadensis*) and black bears (*Ursus americanus*) occurred in the Oquirrhs but were extirpated during the latter 19th century following the introduction of domestic sheep. Both deer and elk are subject to limited annual hunts on the Kennecott portion of the study area. The study site is situated within the Oquirrh-Stansbury Cougar Management Unit, but at the time of the study both properties had been closed to the public and cougar hunting for > 15 years.

Human activities on the Kennecott property are associated with mineral extraction operations. Attendant infrastructure stretched across 32 km with large tracts of intact habitat between. Operations included two pits, two concentrators, an in-pit crusher, an ore smelter, evaporation ponds, leach heaps, access roads, slurry and water lines, a tailings impoundment, and office buildings. All operations were continuously active, including 300-ton capacity haul trucks within the mine, various heavy equipment (dozers, front end loaders, track hoes), and light utility trucks. Most operational activities occurred within 200 m of infrastructure. Camp Williams is operated by the Utah Army National Guard and was used for military training activities. During spring and summer, the camp hosted training battalions of ≥ 300 soldiers 4–6 times a year. Up to 8 artillery exercises were held annually. Various small arms ranges were used year-round. These activities resulted in short fire return intervals on parts of the installation (1–5 yrs). Prominent peaks on the site supported commercial radio and television transmitters with associated access roads used year-round. Based on 2010 census data, human densities (residents/100 km^2) adjacent to the study area varied from 232 in rural Tooele County to 47,259 in urban Salt Lake County (U.S. Census Bureau). The three statistical metro areas that comprise the greater Wasatch Front; Salt Lake City, Provo-Orem, and Ogden-Clearfield, were among the 100 fastest growing American metro areas during 2000–2006.

Capture and Marking

During winter (December to April) from February 1997 to April 2009 we conducted intensive capture efforts by trailing cougars into trees, culverts, cliffs, or mineshafts using trained hounds. Pursuit, immobilization, and handling procedures were conducted in accordance with Utah State University Institutional Animal Care and Use Committee

standards (approval no. 937-R), detailed in Stoner et al. (2006). Cougars were aged using the regression models presented in Laundré et al. (2000). We considered animals 1.5–2.5 years to be sub-adults, and those > 2.5 years as adults. We applied radio collars to all cougars > 40 kg body mass. We used VHF collars throughout the study (*Advanced Telemetry Solutions*, Isanti, MN), but beginning in 2002, we annually marked a subset of 3–4 animals with global positioning systems (GPS) collars (Televilt Simplex or LoTek 4400S). These were programmed to acquire 1 fix every 3 hours beginning at midnight, allowing 120 seconds for each fix attempt. This schedule proved the best compromise between battery life (8–13 months) and monitoring circadian movements. Regardless of type, all collars were equipped with an 8-hour mortality sensor. We tracked radio-collared cougars using aerial and ground-based telemetry techniques at approximately monthly intervals. We recaptured GPS instrumented animals annually to download data and replace collar batteries. Data recorded by GPS Collars included a spatial coordinate (Universal Transverse Mercator, zone 12N, WGS 1984); an associated index of position accuracy, date, and time (Mountain Standard Time year-round). Methods for evaluating GPS position accuracy are detailed in Rieth (2009). We analyzed geographic data in ArcMap v. 9.2 (ESRI, Redlands, California).

Circadian and seasonal movements.—All GPS locations were subsampled by time of day and season. We used time tables from the U. S. Naval Observatory (http://www.usno.navy.mil/USNO/astronomical-applications/) to group hours into three categories based on the timing of sunset and sunrise at Salt Lake City during the winter and summer solstices (40.8° N, 111.9° W, December 21 sunrise: 0748, sunset: 1702; June 22 sunrise: 0456, sunset: 2002). We considered all points recorded between 0800–1600 hrs diurnal; 2000–0400 hrs nocturnal, and 0500–0700 and 1700–1900 hrs crepuscular. We used a 2-hr window to delineate crepuscular points because of seasonal shifts in photoperiod. Because prey distribution influences cougar behavior and habitat use (Pierce et al. 1999) we defined seasons based on mule deer movement patterns. Median mule deer migration dates in the eastern Great Basin occur in late October and mid-May, reflecting the timing of snow accumulation, melt-off, and plant phenology (McClure et al. 2005). As such, we defined the seasonal calendar as: winter = December–May, summer = June–November (Rieth 2009). Lastly, we used a 30-m digital elevation model (DEM) to quantify seasonal elevation shifts.

Predation events and prey composition.—Spatially, we divided the study area into two categories: near-urban environments constituted the "urban-wildland interface" (UWI), defined here as all anthropogenic land-uses with a 500-m buffer, and "wildlands" (WILD), which constituted all lands > 500 m from the UWI. Cougars are known to drag carcasses > 400 m and so the buffer was chosen to adequately capture this behavioral metric (Mondini and Muñoz 2008).

To identify cougar predation events, we used GPS data clusters following the methods detailed by Anderson and Lindzey (2003). GPS coordinates were recorded on internal (store-on-board) collar memory and retrieved upon death, or approximately 1 year after deployment when cougars were recaptured to replace collars. Data points were downloaded into ArcMap to identify, locate, and separate cougar predation events from the data set and produce a map of cougar use locations. This consisted of isolating GPS location clusters comprised of ≥ 2 points within 100 m of each other collected between 2000–0400 hrs, indicative of a nocturnal feeding session. For fieldwork we assumed a radius of 100 m around clusters to account for errors induced by variation in canopy cover, terrain, and animal behavior. To calculate the number of days in association with a particular kill, we subtracted the time of

the first point within 100 m of the cluster center from the last. All points in between these dates were considered temporally dependent on the cache site. The mean of all GPS locations associated with a cluster location was then programmed into a handheld GPS unit and potential cache site locations were visited to determine if a kill had been made. A search was conducted for approximately 30 minutes, covering a radius of ≤100 m from the mean cluster location.

Prey composition was determined through visual inspection of remains found at putative cache sites. Prey remains were identified to species, sex, and age, when possible, from remaining skull and pelvic characteristics following methods described by Schroeder and Robb (2005). Smaller prey items were identified through skull, dental, foot, and long bone characteristics. Date, duration of use, and site descriptions were recorded for each confirmed cache location, including GPS coordinates (UTM), elevation, slope, aspect, distance to closest game trail, and dominant vegetation species.

Cause-specific mortality.—Causes of cougar mortality were determined through visual inspection and necropsy of carcasses. Common causes of death included hunter harvest, agency removal (depredation), poaching, road kill, intra-specific strife, disease, starvation, and injuries sustained during prey capture. When cause of death could not be determined in the field, the carcass was submitted to the Utah Veterinary Diagnostics Lab for detailed analysis (Wolfe et al. 2015). Date of death was determined using the median date between the last two VHF locations or directly from associated GPS data.

Analytical Techniques

Resource Selection Functions.—We estimated cougar resource selection functions (RSF) by season and sex (Manly et al. 1992). The RSF model is based on a use-availability design, in which resource values used by an animal (environmental covariates that underlie a telemetry point) are statistically compared to the total availability of those same values within a defined area. This provides an index of the relative likelihood of use given equal availability. We conducted RSF analyses using the cougar cache site data at two scales: 1) the hunting home range (broad scale); and 2) around each individual cache site (fine scale). For the broad scale analysis, we sampled resources within minimum convex polygons (MCP) delineated by the distribution of cache locations for each cougar in winter and summer. Individual MCPs were buffered by 800 m to account for GPS position errors and animal movements around cache sites. The resultant sampling frame was based on animal use patterns with fitness consequences (i.e. hunting and feeding). For the fine scale RSF, we buffered each cache location by 400 m (winter) or 330 m (summer), reflecting mean distances between cache sites and contemporaneous daybeds. For both analyses we generated 'available points' using a random sample with the "spsample" function in the sp package in program R (R Development Core Team 2020; Pebesma and Bivand 2005). For the broad scale analysis, the number of random points within each MCP was based on the size of each cougars' seasonal hunting home range size at a density of 100 random points per km^2. For the fine-scale analysis we generated 100 random locations within the buffered areas of each cache site.

Within the RSF framework we evaluated cougar habitat use with respect to seven variables. These included deer habitat, distance to urban areas, distance to mining, distance to agriculture, distance to rural paved roads (i.e. paved roads within the "urban" variable were not included), distance to dirt roads, and shrub habitat. For summer models 'deer

habitat' was replaced with Normalized Difference Vegetation Index (NDVI). We converted categorical variables to continuous by measuring cougar response in terms of 'distance to'. As such, negative coefficients imply cougar use of habitats that are closer to those features than would be expected by chance. Positive coefficients imply the opposite.

Mule deer are the preferred prey of cougars over much of the West, and as such their presence influences cougar space use (Pierce et al. 1999; Mitchell 2013). Lacking a concurrent sample of marked animals our ability to predict deer presence was limited to the use of an index. We assumed that the presence and abundance of deer during winter would be most predictable on sites with ephemeral snow cover and specific vegetative cover (Parker et al. 1984; Monteith et al. 2011; Fig. 2A). We defined winter deer habitat as southwestern aspects (135°–270°) comprised of mountain shrubs and piñon-juniper woodlands with ephemeral snow cover (Robinette et al. 1952). We created a binary "shrub" layer by reclassifying all landcover types within the Southwest ReGAP data (USGS 2004) that included sagebrush, bitterbrush, Gambel oak, or mountain mahogany (Rieth 2009). We used a 30-m digital elevation model to calculate aspect, and overlaid this with the inverse of mean 8-day 500 m snow cover averaged for each winter season on our site (MOD10A2 v006; Hall and Riggs 2016). The result was a single predictor variable that represented warm aspects (all other slope faces = 0) with increasing values in areas with little or ephemeral winter snow cover. Mean winter snow cover data were assigned the year of the cougar-season cache site data for the broad scale analysis, or the year for winter cache sites in the fine-scale analysis. For summer models we used mean seasonal NDVI, a measure of vegetative greenness, and shrub-dominated habitat as indices of deer habitat. Mean summer NDVI data were collected at 250 m resolution every 16 days (MOD13Q1 v006; Didan 2015) and aligned with contemporaneous cache site data.

We measured several variables representing the human footprint based on anthropogenic land uses that formed an ecotone with native vegetation or terrain. We identified three general sub-categories of human land use and two road types. These were: 1) "urban" (residential, industrial, and commercial buildings and facilities associated with predictable human activity; Fig. 2B), 2) "mining" (lands currently or historically used for open pit mining and associated tailings, leach heaps, and rehabilitated lands), and 3) "agriculture" (all cultivated lands including farms, ranches, pasture, and unirrigated cropland). Other small, localized

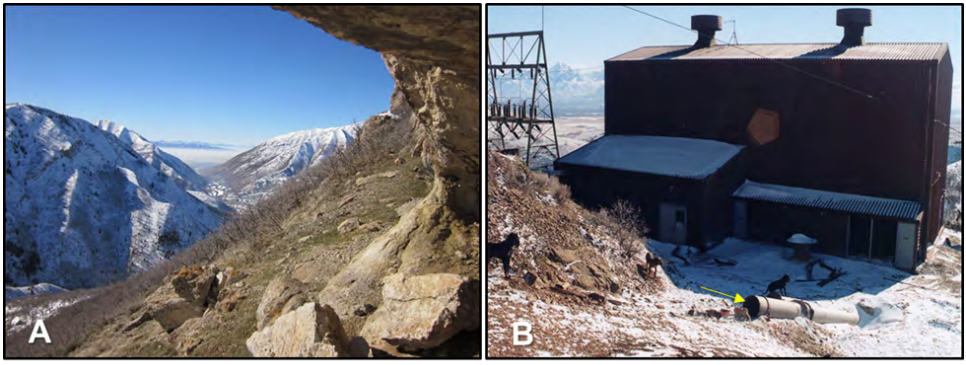

Figure 2. (A) Ephemeral snowpack makes south-facing aspects attractive to mule deer during winter months. (B) Cougars used abandoned buildings such as this mining shed, especially during captures (arrow indicates location of bayed cougar; photos: D. Mitchell and D. Stoner).

anthropogenic land uses such as disturbed ground, shooting ranges, junkyards, gravel pits, and water tanks were excluded. We used 5-m resolution color digital orthophoto quads collected August 2006 to digitize polygons around each anthropogenic land-use, and then buffered each polygon by 100 m to account for imagery error (https://www.usgs.gov/centers/eros/science/). We used shapefiles delineating the distribution of both dirt and paved roads around the study site (https://gis.utah.gov/#data). To measure distance, we used the 'path distance' function in ArcGIS combined with a 30-m digital elevation model to index cougar response to selected predictor variables. This tool estimates the shortest distance between the edge of a polygon and the neighboring cell, while minimizing variation in elevation. The output was a set of grids in which each cell value represented a distance to the nearest human land-use variable, collectively referred to as the "urban-wildland interface" (UWI).

We used the 'extract' function from the raster package (Hijmans 2020) in program R (R Core Team v.3.13.0) to extract values from the distance-based UWI raster grids and the deer habitat variables for all cache site locations and random points associated with both analyses. For all RSF analyses the response variable was binary, whereby cache sites were given a value of "1" and random locations were assigned a value of "0". All RSF models were fit using a weighted likelihood, in which the variable in the "weights" argument was assigned a value of 1000 exponentiated to the power of [1 – number of used cache locations] (Muff et al. 2020). For broad-scale analyses we created mixed models, one for each season, that included all five UWI variables, deer habitat variables, and a random intercept for each unique cougar ID. We assessed whether male and female cougars differ in their relationships to various components of the UWI by including an interaction term between sex of the individual and the four human land-use variables that we hypothesized may have the largest effects (distance to: paved road, urban, mining, and agriculture). We used the 'glmer' function in the R package lme4 (Bates et al. 2015) to create summer and winter models. Because our fine scale models assessed how the same set of covariates influenced cache site locations using 330–400m buffers, we took a less conservative modeling approach by assuming each kill and associated cache site were independent (no random effect for ID). Consequently, we used the 'glm' function to fit the fine-scale RSF models. Prior to running the models all variables were assessed for high levels of correlation (all pairwise correlations were < 0.7 so all were retained; Dormann et al. 2013) and each was centered and scaled by the mean and SD for comparative purposes. For both the broad and fine scale seasonal analyses, we fit global models based on a priori hypotheses about cougar cache site selection. Each covariate and interaction within the models were evaluated for significance using 95% confidence intervals and p-values.

We used our broad scale RSF models to generate seasonal suitability values across the study area without the interactions between sex and human land-use variables. For each cougar, we calculated predicted RSF values by taking the product of the corresponding coefficients from each seasonal model and spatial data (deer habitat, land-use type, roads). We resampled spatial layers with coarse resolutions to 30 m with a bilinear method. The resulting products for each grid cell were summed and plotted based on the quantile range determined using all predicted RSF values within each seasonal model. Lastly, we subtracted the summer from the winter model to illustrate seasonal changes in cougar resource selection solely on UWI land-uses.

Prey composition.—To evaluate dietary habits we tallied the number of carcasses of each species detected based on location and compared the proportional occurrence of each prey species with respect to land use, season, and sex (2002–2010). We pooled kills across

individuals and subdivided them by location (UWI, WILD). We made statistical comparisons for the most common prey species using a chi-square test of equal proportions.

Mortality.—We compared cause and sex-specific mortality between UWI and WILD land-use types. Causes were classified as either 'human' (harvest, poaching, roadkill, and depredation control) or 'natural' (starvation, injury, disease, strife). Statistical comparisons of proportional differences were made using chi-square tests. We then evaluated differences in the age of cougars at the time of death by land-use type using Analysis of Variance. We report descriptive statistics as mean ± SD unless otherwise noted. All statistical tests were conducted using R software (R Development Core Team 2020).

RESULTS

Capture and Marking

From 1997–2009, we marked 79 cougars during 146 capture events. Within this sample, 41 individuals were collared with VHF (21 F, 20 M; 1997–2009), and 24 with GPS instruments (17 F, 7 M; 2002–2009). Fourteen kittens were marked solely with ear tattoos (7 F, 7 M). Four additional unmarked cougars were found dead during tracking, including 2 adults (1 F, 1 M), 1 subadult female, and 1 male kitten. Mean monitoring time of collared animals ranged from 8-3,286 days (F = 926 ± 895 days; M = 564 ± 476 days). Three GPS cougars were censored because of early mortality (1 F) or equipment failure (2 M). Data from the remaining GPS instrumented cougars comprised 1,257 animal-weeks (1,043 F, 214 M), and 38,796 locations. GPS collar acquisition fix success ranged from 19.7–86.1%, and averaged 56.5 ± 20.9% for resident females (n = 15), and 53.6 ± 15.7% for males (n = 5). From these data we identified 910 potential cache sites, of which 85% were field-truthed, resulting in the location of 540 prey items (UWI = 175; WILD = 365). The proportion of successful cluster searches was similar between land uses (UWI = 51%; WILD = 56%). Habitat selection and prey composition analyses were based solely on GPS collared animals (n = 21), whereas movement and mortality analyses used data from both VHF and GPS collared individuals (n = 42).

Circadian and Seasonal Movements

Cougar elevational use varied both daily and seasonally. Nocturnal positions averaged 65 m lower than diurnal positions (1,853 ± 94 m vs. 1,918 ± 102 m), and were consequently 118 m closer to human activities at night. This pattern did vary, most notably in that males tended to be closer to the UWI during the day than at night in summer, whereas females displayed the opposite pattern during all seasons. Mean cougar elevational use was 205 m lower in winter than summer (1,885 ± 93 m vs. 2,090 ± 193 m), likely a result of snow induced movements by their primary prey. This resulted in a mean lateral shift of 584 m (± 650 m) eastward and therefore closer to the UWI. For the pooled sample mean distance to the UWI was 1,717 ± 872 m during summer, decreasing to 1,191 ± 489 m in winter.

Hypothesis 1. Cougar Habitat Selection by Land-use Type

RSF models illuminated notable differences in the way cougars used and reacted to different land-uses (Table 1). At the scale of the home range, indices of deer habitat were significant in both seasons, but several variables associated with the UWI also explained

Table 1. Model results for cougar resource selection functions at the scale of the hunting home range, by season; Oquirrh Mountains, Utah, 2002–2010.

Season	Variable	Beta estimate	95% CI	Z	p
Winter	Intercept	-12.59	(-13, -12.19)	-60.37	< 0.01
	Deer Habitat	0.24	(0.15, 0.32)	5.49	< 0.01
	Dist. Dirt Road	0.00	(-0.13, 0.12)	0.00	1.00
	SEX: Males	-1.09	(-1.92, -0.26)	-2.57	0.01
	Dist. Paved Road	-0.16	(-0.33, 0)	-1.91	0.06
	Dist. Urban	-0.19	(-0.36, -0.01)	-2.11	0.03
	Dist. Mining	-0.43	(-0.62, -0.24)	-4.40	< 0.01
	Dist. Agriculture	0.39	(0.22, 0.56)	4.41	< 0.01
	Shrub Habitat	0.19	(0.1, 0.29)	3.93	< 0.01
	SEX:Males X Dist. Paved Road	0.13	(-0.26, 0.52)	0.65	0.51
	SEX:Males X Urban	0.11	(-0.29, 0.5)	0.52	0.60
	SEX:Males X Dist. Mining	0.23	(-0.12, 0.57)	1.27	0.20
	SEX:Males X Dist. Agriculture	-0.72	(-1.11, -0.33)	-3.63	< 0.01
Summer	Intercept	-12.03	(-12.29, -11.77)	-89.65	< 0.01
	NDVI	0.57	(0.38, 0.76)	6.01	< 0.01
	Dist. Dirt Road	0.02	(-0.1, 0.14)	0.36	0.72
	SEX: Males	-1.37	(-1.95, -0.79)	-4.60	< 0.01
	Dist. Paved Road	0.34	(0.16, 0.52)	3.65	< 0.01
	Dist. Urban	-0.15	(-0.3, 0.01)	-1.89	0.06
	Dist. Mining	-0.97	(-1.17, -0.76)	-9.27	< 0.01
	Dist. Agriculture	0.25	(0.08, 0.43)	2.81	< 0.01
	Shrub Habitat	0.38	(0.26, 0.51)	6.21	< 0.01
	SEX:Males X Dist. Paved Road	-0.48	(-0.92, -0.04)	-2.15	0.03
	SEX:Males X Urban	0.36	(-0.03, 0.76)	1.79	0.07
	SEX:Males X Dist. Mining	0.61	(0.2, 1.01)	2.95	< 0.01
	SEX:Males X Dist. Agriculture	-0.37	(-0.74, -0.01)	-2.00	0.05

cougar habitat use. In general, females showed stronger responses to human land-use variables than males. Mined areas were strongly selected for by females during both seasons, but males only selected for this land use type during summer. Females used habitats closer to urban areas in both seasons, although the relationship was only marginally significant during summer ($p = 0.06$). Males did not show selection for or against these areas. In summer, females strongly avoided paved roads, but males weakly selected for them. Female cougars avoided agriculture year-round, whereas males showed greater tolerance of cultivated land uses relative to females during winter. Cougars demonstrated no discernable reaction to dirt roads in any season. A spatial depiction of model results (sexes pooled) is illustrated in Fig. 3. When viewed in terms of seasonal changes in selection, collectively, cougars increased their use of the UWI by 17% from summer to winter (Fig. 4).

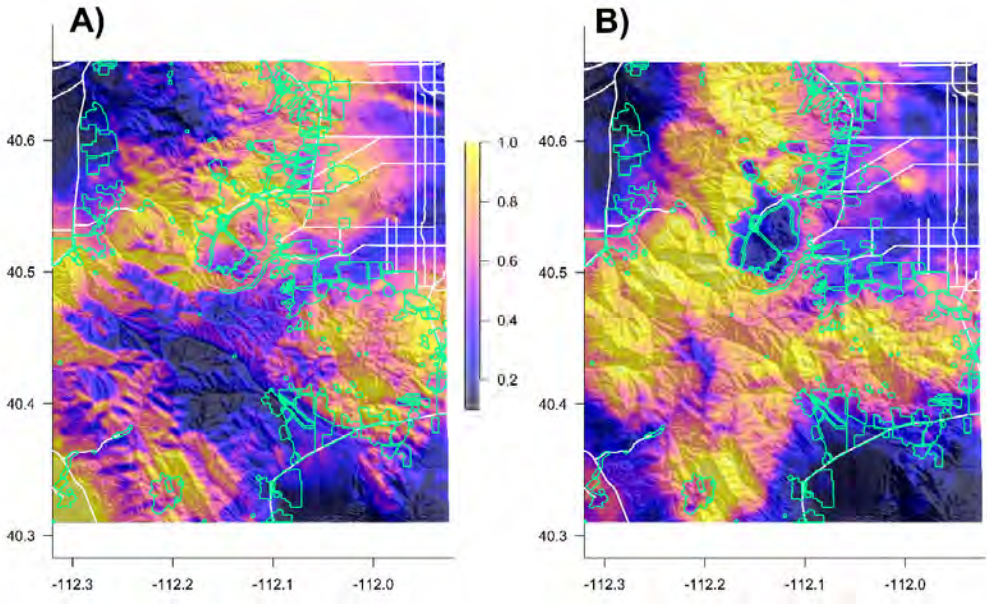

Figure 3. Resource selection functions predicting cougar hunting habitat during (A) winter, and (B) summer in the Oquirrh Mtns, Utah (2002–2010). Areas with the highest probability of use are depicted in yellow, with cooler colors reflecting lower use; white lines are paved roads; green polygons represent anthropogenic land-uses surrounding the study area (urban, mining, agriculture).

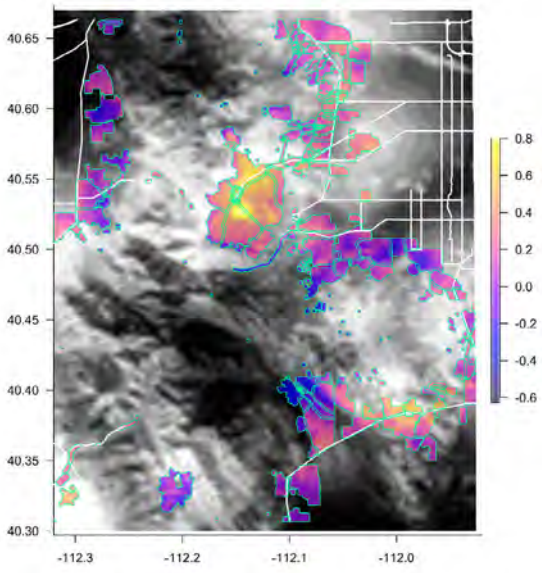

Figure 4. Relative changes in cougar habitat selection between seasons. Predicted resource selection by cougars within urban-wildland interface environments increased by 17% from summer to winter. Green polygons represent urban-wildland interface environments; warm colors within those polygons indicate relatively higher probability of use by cougars. This approach can be used to identify potential conflict hotspots and prioritize public education campaigns to reduce the availability of food attractants.

At the scale of the cache site, only variables related to the presence of deer had any influence on model results, i.e. within a 330–400 m radius (summer and winter, respectively) of cache sites, no UWI variables were significant (Table 2).

Table 2. Model results for cougar resource selection functions at the scale of the cache site, by season; Oquirrh Mountains, Utah, 2002–2010.

Season	Variable	Beta estimate	95% CI	Z	p
Winter	Intercept	–11.53	(–11.62, –11.44)	–250.95	< 0.01
	Deer Habitat	0.18	(0.10, 0.27)	4.19	< 0.01
	Dist. Dirt Road	0.01	(–0.08, 0.11)	0.28	0.78
	Dist. Paved Road	–0.01	(–0.16, 0.14)	–0.14	0.89
	Dist. Urban	–0.01	(–0.17, 0.15)	–0.11	0.91
	Dist. Mining	0.01	(–0.11, 0.13)	0.14	0.89
	Dist. Agriculture	–0.03	(–0.15, 0.09)	–0.50	0.61
	Shrub Habitat	0.12	(0.02, 0.21)	2.40	< 0.01
Summer	Intercept	–11.53	(–11.63, –11.44)	–241.57	< 0.01
	NDVI	0.03	(–0.09, 0.15)	0.54	0.59
	Dist. Dirt Road	0.02	(–0.09, 0.12)	0.28	0.78
	Dist. Paved Road	–0.01	(–0.14, 0.11)	–0.17	0.87
	Dist. Urban	–0.01	(–0.15, 0.14)	–0.09	0.93
	Dist. Mining	–0.02	(–0.17, 0.14)	–0.20	0.84
	Dist. Agriculture	–0.03	(–0.16, 0.10)	–0.45	0.65
	Shrub Habitat	0.20	(0.09, 0.31)	3.63	< 0.01

Hypothesis 2. Prey Composition by Land-use Type

We detected a total of 17 species in cougar cache sites (Table 3). Mule deer were the most common prey species (n = 463), followed by elk (n = 39), and coyotes (n = 7). Domestic species included cattle (n = 6), sheep (n = 4) and goats (n = 1). Mule deer comprised similar proportions of all species killed in both UWI and WILD settings (87.4% vs. 84.9%; $\chi^2 = 0.42$, $df = 1$, $p = 0.52$; Table 3). Within the UWI kill sample (all species combined), the proportion comprised of mule deer was similar between seasons (86.0% vs. 90.6%; $\chi^2 = 0.33$, $df = 1$, $p = 0.56$). However, after controlling for species, a greater proportion of the total deer kill occurred in WILD settings than UWI (66.9% vs. 33.1%; $\chi^2 = 105.1$, $df = 1$, $p < 0.001$). Seasonally, more deer were killed during winter than summer, regardless of land-use (62.2% vs. 37.8; $\chi^2 = 54.2$, $df = 1$, $p < 0.001$; Fig. 5). Elk only represented 7.2% of the total kill, but within this subsample, they were killed predominantly in WILD settings (82.1% vs. 17.9%; $\chi^2 = 29.5$, $df = 1$, $p < 0.001$). Sample sizes were too small to make comparisons by sex.

Table 3. Prey remains found in urban-wildland interface (UWI) and wildland (WILD) environments, by species, Oquirrh Mountains, Utah, 2002–2010 ([1] species unidentified).

Species	Prey remains by land-use type			
	(n)	UWI	(n)	WILD
mule deer	153	87.4%	310	84.9%
elk	7	4.0%	32	8.8%
coyote	4	2.3%	3	0.8%
skunk	2	1.1%	0	0.0%
turkey	2	1.1%	2	0.5%
canid[1]	1	0.6%	1	0.3%
red fox	1	0.6%	2	0.5%
goat	1	0.6%	0	0.0%
marmot	1	0.6%	0	0.0%
porcupine	1	0.6%	0	0.0%
raccoon	1	0.6%	0	0.0%
dom. sheep	1	0.6%	3	0.8%
bobcat	0	0.0%	1	0.3%
cattle	0	0.0%	6	1.6%
cougar	0	0.0%	3	0.8%
lagomorph	0	0.0%	1	0.3%
raptor[1]	0	0.0%	1	0.3%

Hypothesis 3. Cause-specific Mortality by Land-use Type

Given the proximity of this population to an array of human activities and land-uses, we assumed mortality would be primarily human caused. To evaluate this hypothesis, we pooled all animals for which cause of death could be ascertained (n = 25 VHF, 14 GPS, 3 unmarked individuals), and made comparisons by cause (human vs. natural), sex (males vs. females), land-use (UWI vs. WILD), and season (winter vs. summer). We documented 42 mortalities, of which 13 were human-caused (Table 4). Proportions of human vs. natural causes differed from parity (30.9% vs. 69.1%; $\chi^2 = 5.3$, $df = 1$, $p = 0.02$), but males were more likely to die of human causes than females (52.9% vs. 16.1%; $\chi^2 = 4.5$, $df = 1$, $p = 0.03$). Among land-use types, cougar mortalities occurred disproportionately in WILD environments (78.6% vs. 21.4%; $\chi^2 = 12.6$, $df = 1$, $p < 0.001$). Differences in season were also evident, with 90% of all deaths taking place during winter; of these 76% occurred in wildland settings, with 83% of those were due to natural causes.

Cougar mortalities occurring on the UWI were largely human-caused (F = 60%, M = 100%), stemming from roadkill and depredation control. Age structure of animals dying in UWI environments differed by sex. Females were significantly older (11.2 ± 2 vs. 6.1 ± 3.5 yrs; $F = 8.8$, $df = 1$, $p = 0.007$), and males were significantly younger than their counterparts that died in wildland settings (1.6 ± 1.1 vs. 5.4 ± 1.2 yrs; $F = 25.1$, $df = 1$, $p < 0.001$; Fig. 6).

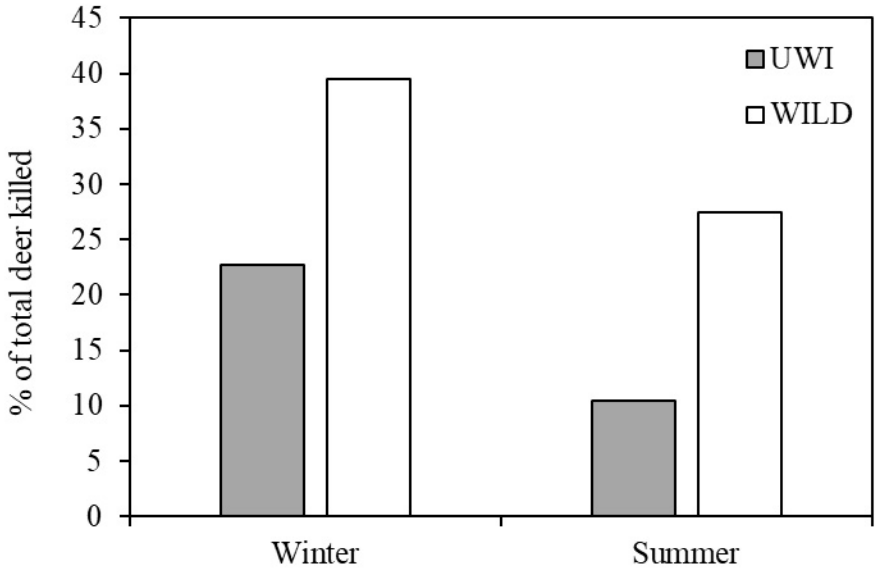

Figure 5. The relative proportions of the total mule deer kill, by season and land-use (n = 463; categories sum to 100%). More deer were killed in wildland settings during winter than any other season × land-use combination.

Table 4. Cause-specific cougar mortality by sex, age, season, and land-use (n = 42); Oquirrh Mountains, Utah, 2002–2010.

			Mortality		
Sex	Age	Cause	Type	Season	Land-use
F	10	roadkill	human	winter	uwi
F	11	roadkill	human	winter	uwi
F	11	roadkill	human	winter	uwi
F	6	poach	human	winter	wild
F	14	malnutrition	natural	winter	uwi
F	9	malnutrition	natural	winter	uwi
F	1	disease	natural	winter	wild
F	2	strife	natural	spring	wild
F	2	malnutrition	natural	winter	wild
F	3	prey	natural	spring	wild
F	3	strife	natural	winter	wild
F	3	malnutrition	natural	winter	wild
F	4	strife	natural	winter	wild
F	5	strife	natural	winter	wild
F	6	prey	natural	spring	wild
F	7	prey	natural	fall	wild
F	7	malnutrition	natural	winter	wild

Table 4 continued.

			Mortality		
Sex	Age	Cause	Type	Season	Land-use
F	7	strife	natural	spring	wild
F	9	malnutrition	natural	fall	wild
F	9	malnutrition	natural	winter	wild
F	10	malnutrition	natural	winter	wild
F	10	strife	natural	spring	wild
F	13	malnutrition	natural	summer	wild
F	12	malnutrition	natural	winter	wild
F	3	strife	natural	winter	wild
M	1	control	human	winter	uwi
M	1	roadkill	human	winter	uwi
M	2	control	human	spring	uwi
M	3	control	human	winter	uwi
M	4	harvest	human	winter	wild
M	5	harvest	human	winter	wild
M	5	harvest	human	winter	wild
M	6	harvest	human	fall	wild
M	6	harvest	human	winter	wild
M	4	strife	natural	winter	wild
M	4	strife	natural	spring	wild
M	5	prey	natural	spring	wild
M	6	prey	natural	spring	wild
M	7	strife	natural	winter	wild
M	7	prey	natural	spring	wild
M	3	strife	natural	winter	wild
M	na	malnutrition	natural	spring	wild

DISCUSSION

Cougar Habitat Selection by Land-use Type

Western ecosystems are bounded by climatic extremes of drought and heavy snowpack, which affect ungulate movement, habitat use, and population trends. As predicted, cougar behavior mirrored that of their major prey (Pierce et al. 1999). In the anthropogenically altered environments of the Oquirrh Mountains, cougars displayed the strongest associations with habitats that provided hunting advantages or the predictable presence of mule deer (Coon et al. 2019; Ditmer et al. 2020). These patterns were not limited to wildland environments, however, and human-land-uses that mimicked ambush habitat, such as mined areas were readily integrated as habitat. Although we found no evidence of resident cougars systematically traveling through, or foraging directly in urban settings, they did use the UWI, particularly

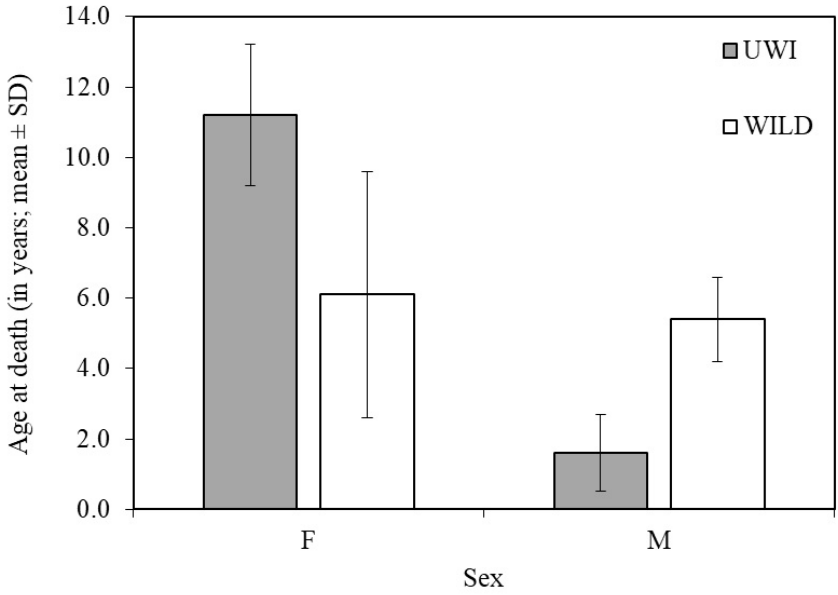

Figure 6. Mean age at time of death (± SD) for female and male cougars in UWI and WILD environments. Females dying of any cause on the UWI were significantly older than those dying in wildlands (n = 5), whereas among males, animals dying on the UWI were significantly younger than those dying in wildlands (n = 4). Males (n = 13) and females (n = 20) dying in wildland environments did not differ in age.

in winter, when deer occupied low elevation ranges, suggesting that despite human activity, these environments had some foraging value to cougars.

The strong attraction to mined areas has two potential explanations. First, mining and associated reclamation activities most closely approximate the habitat features that cougars seek for hunting (Rieth 2009). The juxtaposition of steep slopes with abrupt ecotones supporting early successional plant communities attracts ungulate prey. Indeed, the use of mined landscapes by three of the most important ungulate prey for cougars has been widely reported, and suggests that rehabilitated sites away from active excavation can be important habitat for mountain ungulates (Olsson et al. 2007; Bleich et al. 2009; Blum et al. 2015). Second, the use of mined areas may indicate presence of an abundant, energetically rewarding alternative prey species, such as marmots (*Marmota flaviventris*: e.g., Branch et al. 1996). These explanations are not mutually exclusive, but the association with this landscape feature was most pronounced among females during both seasons.

Seasonal use of urban and agricultural lands by ungulates is common in the mountain West (McClure et al. 2005; Anderson et al. 2012; Polfus and Krausman 2012), and in our study area these land-uses were bounded by paved roads connecting outlying suburbs to Salt Lake City. We found 10 cache sites within 200 m of a highway or railroad, and model results indicated that female cougars exhibited weak selection for rural paved roads in winter. These results suggest that cougars had higher hunting success in certain parts of the UWI, or that they exploited other foraging opportunities that did not require extensive search or travel times. Notably, in winter commuter traffic is heaviest during crepuscular hours when deer are most active, resulting in the production of carrion in certain predictable localities (Kassar and Bissonette 2005). At this scale, our predictions that cougars would select for

WILD over UWI habitats were largely supported, but not the exclusion of other land-uses occupied by their principal prey.

Prey Composition by Land-use Type

Patterns in prey composition were similar between UWI and WILD settings with some notable exceptions. Despite cougar selection for UWI habitats, domestic animals were poorly represented in our sample. One goat was killed on the UWI, but all free-roaming sheep and cattle were consumed in wildlands. Among native ungulates, elk were disproportionately killed in wildlands, largely reflecting their distribution, but mule deer comprised similar proportions of the observed kill across land uses. Only variables related to deer habitat were significant in RSF models performed at the scale of the cache site (330–400 m buffer). Combined with the dearth of domestic ungulates in both UWI and WILD settings, this suggests that most cougar use of UWI environments was in pursuit of native prey, rather than pets or livestock (Ditmer et al. 2020). By using the UWI, female cougars may have been capitalizing on scavenging opportunities and vulnerable mule deer (Farnsworth et al. 2005; Krumm et al. 2010), avoiding conspecifics (Benson et al. 2016), or making trade-offs related to reproductive state (Bunnefeld et al. 2006). That said, other diet studies have documented extensive use of small prey, human commensals, and domestic species in UWI environments (Kertson et al. 2011; Moss et al. 2016). Unfortunately, our results are not directly comparable to those efforts, as our sampling methods were biased against small prey items (Stiner et al. 2012). We therefore cannot exclude the possibility that cougars were exploiting food resources other than adult deer, such as feral house cats (*Felis catus*; Wolfe and Stoner, unpublished data) or other mesocarnivores. Given the importance of small to mid-sized prey for females and subadults (Benson et al. 2016; Moss et al. 2016), these results may underestimate the value of non-ungulate prey in UWI environments for certain demographic classes.

Cause-specific Mortality by Land-use Type

Human impacted landscapes have been identified as carnivore population sinks as a result of conflicts stemming from food attractants in the form of livestock or garbage (Woodroffe and Ginsburg 1998). Our results offer a mixed view of this argument. Consistent with other studies conducted in non-wilderness landscapes (Thompson et al. 2014; Vickers et al. 2015; Moss et al. 2016; Benson et al. 2020), roadkill and depredation control were the most common anthropogenic mortality factors (54% of human-caused deaths), but only accounted for 17% of all recorded deaths. Similarly, poaching has been documented in nominally-protected populations (Vickers et al. 2015; Benson et al. 2020), but represented only a minor source of mortality in our sample (n = 1). Hunter harvest occurred in this population (n = 5), but was limited to public wildlands adjacent to the study site. When viewed demographically, the distribution of human-caused mortality was bi-modal. All males killed on the UWI were subadults, of which one was handicapped, one orphaned, and the other malnourished. Females showed a remarkable pattern, in which those that died in UWI settings succumbed exclusively to malnutrition and vehicle strikes. In stark contrast to males, females ranged in age from 9–14 years, of which at least two had dependent offspring at the time of death.

These causes are likely related. The canine teeth of cougars exhibit breakage and wear with age (Fig. 7), and roadside carcasses have extensive soft tissue damage, making them easier to locate and consume. All cougar-vehicle collisions (n = 4) occurred in two distinct locations, each with an underpass that offered more cover than at-grade crossings. Both

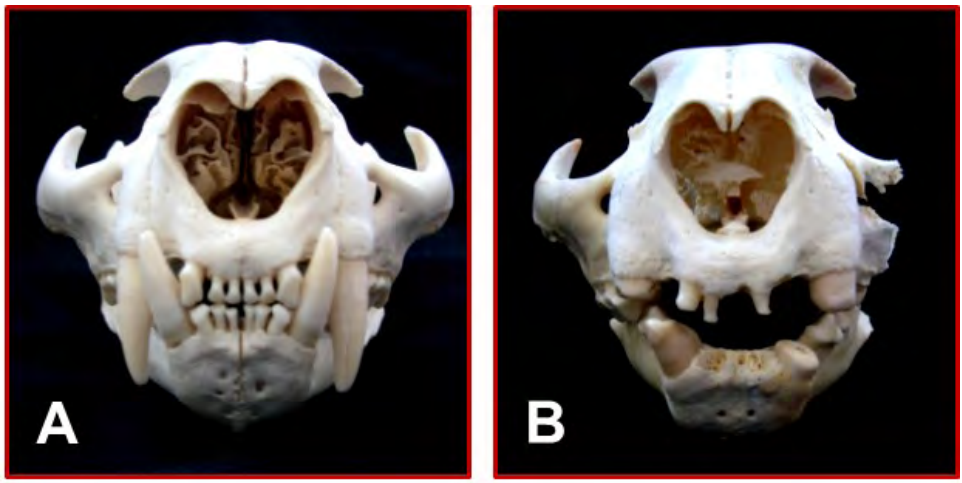

Figure 7. Dental wear may be a factor influencing individual habitat selection and use of anthropogenic food resources in the urban-wildland interface. Note differences in tooth loss, canine breakage, and wear between (A) F51, a 3-yr old that died during prey capture, and (B) F12, a 10-yr old hit by an automobile during early kitten rearing.

sites have been identified as "roadkill hotspots," producing ≥ 1.9 deer carcasses / km / yr across 18 km of highway (Kassar and Bissonette 2005; Fig. 1), underscoring the possibility that, rather than simply crossing the highway, these animals were foraging along the roads themselves. We documented such a phenomenon in 2002 when a maternal female made repeated trips over a 13-day interval to feed on road-killed deer in a cemetery adjacent to the study site. The combination of increased energetic demands associated with maternity and extensive dental wear may have motivated these individuals to seek low-risk, manageable prey items most readily available in the form of carrion. Notably, across the study period female survival rates were high (mean = 0.77 ± 0.05; Wolfe et al. 2015) and density was constant (Stoner et al. 2006). Thus, despite proximity to one million people, cougars that died on the UWI largely represented compensatory mortality, being inefficient hunters, best exemplified by the very young and the very old.

Our results differ from other studies conducted in UWI settings, in that mortality resulted largely from natural causes, including intraspecific strife, and injuries followed by starvation. Reasons for these discrepancies are speculative, but likely stem from variation in the size and arrangement of the focal UWI environments. For example, in Northern California, Washington, and Colorado, housing was interspersed with forested landscapes, resulting in a more heterogenous mix of land-uses (Kertson et al. 2011; Wilmers et al. 2013; Moss et al. 2016), whereas cougar populations in Southern California are small, isolated, and exhibit hard boundaries with residential housing (Vickers et al. 2015; Benson et al. 2020). In contrast, the Oquirrh site was bounded by flat, open agricultural lands on the east, and steep, unroaded BLM lands on the west, which formed a large buffer around the site effectively increasing the size of the protected area.

Conclusions

Given the history of conflict between predators and agrarian societies, the ability of a large, potentially dangerous carnivore to persist on the periphery of a major American city

may seem contradictory. Ecological anomalies and potential threats to this population included commuter traffic, wildfires, persistent habitat loss, and light pollution (Mitchell 2013; Ditmer et al. 2020). Yet within this environment, cougars used vacant buildings, culverts, and mineshafts as den, rest, and cache sites; they hunted native prey near urban areas, scavenged roadkill, and one subadult male successfully dispersed across an 8-lane interstate. Despite their ready availability, domestic ungulates represented only 2% of recovered kills, and no attacks on humans occurred. Our results add to a growing body of research that attests to the species' ability to navigate heavily disturbed, urban and post-industrial landscapes (Knopff 2014). Thus, contrary to expectations, this population did not fit the profile of an attractive sink or one unduly influenced by edge effects (Woodroffe and Ginsburg 1998, Woodroffe 2000), rather it better approximated the "stability phase" articulated by Linnell et al. (2001), in which regulatory mechanisms, in this case the exclusion of hunting or livestock depredation control on military and industrial properties, allowed this population to persist in the face of high human densities. These findings make it difficult for us to imagine the scenario hypothesized by Ripple and Beschta (2006) in which the predictable presence of humans, unaccompanied by direct lethal consequences, has the capacity to suppress densities or cause abandonment of areas that otherwise exemplify cougar habitat. Indeed, our data suggest just the opposite; that individuals with physical maladies or during certain life stages may exploit foraging opportunities associated with human activities.

Management Implications: Conflict or Coexistence?

Cougar management is complicated by simultaneous and sometimes incompatible directives focused on minimizing human-wildlife conflict, while conserving populations vulnerable to extirpation. The unique configuration of human land-uses and small area of our site make inference to other UWI cougar populations questionable. That said, trends in urban growth, spatial variation in human-caused mortality, and climate suggest three findings of our work that may be generalizable. First, the strongest predictor of cougar habitat use at all scales was the presence of mule deer. Concurrent work suggests that cougars readily exploit urban deer populations by hunting the dark fringes of the UWI (Ditmer et al. 2020). In drought-prone areas use of irrigated landscapes combined with post-fire plant succession create conditions highly attractive to deer (Roerick et al. 2019). Although urban deer represent one of the most vexing problems faced by state wildlife agencies, reducing this attractant is the single largest variable managers can influence to reduce potential conflict with cougars. Second, in jurisdictions where hunting is either prohibited, such as California, or constrained by land ownership patterns (e.g. Salt Lake City; Stoner et al. 2013), cougars may reach advanced ages not seen in hunted populations. Under these conditions, tooth wear and malnutrition may prompt cougar use of predictable food sources in urban areas. Third, climate predictions for the Southwest indicate a drying trend associated with increased variability in precipitation (Seager et al. 2007). Consequently, drought and heavy winters will continue to shape animal movements in the region. Land-use policies that conserve open space buffers between wildlands and residential areas may afford agency personnel greater latitude for managing deer in mixed-use environments. To increase public support, we suggest development of crowd-sourced, camera-based networks for monitoring trends in species distribution and abundance. When combined with predictive maps of land-use change (e.g. Sexton et al. 2013), the monitoring system could be used to proactively target education campaigns focused on reducing food attractants to deer and other prey species, identify connective habitats, and mapping conflict hotspots (Fig. 4).

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FULL RESEARCH ARTICLE

The case for case studies: A new approach to evaluating the effectiveness of livestock protection tools

DAN MACON[1]* AND CAROLYN WHITESELL[2]

[1] *University of California Division of Agriculture and Natural Resources – Placer-Nevada-Sutter-Yuba, 11477 E Ave, Auburn, CA 95603, USA*

[2] *University of California Division of Agriculture and Natural Resources—San Mateo-San Francisco Counties, 1500 Purisima Creek Road, Half Moon Bay, CA 94019, USA*

**Corresponding Author: dmacon@ucanr.edu*

Livestock operations in California face livestock losses due to a range of carnivore species. Simultaneously, there is an increased call to reduce the use of lethal predator control methods and replace them with nonlethal methods. Livestock guardian dogs (*Canis lupus familiaris*) are one such nonlethal livestock protection tool (LPT), yet research is still lacking on the factors and situations that impact their effectiveness. Using three case studies, we demonstrate the value of objective analyses that explicitly address the inherent differences in ranch management, environment, and surrounding land uses in examining livestock guardian dogs as an LPT. We used semi-structured questionnaire surveys of livestock operators to collect information on effectiveness, behavior, and producer satisfaction of LGDs protecting poultry (*Gallus gallus domesticus*), calves (*Bovus taurus*), and sheep (*Ovis aries*) on private and public land and in conjunction with a variety of other livestock protection tools. We aimed to address all aspects related to the use of LGDs as a means of informing livestock operators' decisions on whether LGDs are an appropriate tool for a particular operation. The case studies demonstrated the complexities involved in applying LGDs as a LPT within the context of a livestock operation. In two of the three case studies, LGDs did not entirely eliminate livestock losses yet operator satisfaction remained high.

Key words: human-wildlife coexistence, livestock depredation, livestock guardian dog, livestock protection tools

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Livestock operations throughout California regularly face conflict with predators such as coyotes (*Canis latrans*), mountain lions (*Puma concolor)*, black bears (*Ursus americanus)*, bobcats (*Lynx rufus*), and (in northeastern California) gray wolves (*Canis lupus*). These conflicts are often intensified by public policy and perceptions that limit lethal predator

control options for livestock producers (Macon 2020). Consequently, many producers are increasingly turning to a variety of nonlethal livestock protection tools (LPTs), including livestock guardian dogs (LGDs) (*Canis lupus familiaris*), to protect their herds and flocks from predators. Objective evaluation of the efficacy of nonlethal LPTs, however, is extremely challenging, especially in a real-world setting. Every ranching operation – even those adjacent to one another – is different in terms of environmental variables, operational goals, management capacity, production calendars, livestock genetics, and many other parameters. The challenges inherent in utilizing randomized case-control study largely reflect the inability to control these variables within or between livestock operations (Ecklund et al. 2017). Furthermore, ethical considerations and economic pressures make designating an unprotected "control" group impractical and morally hazardous. After all, who wants to sacrifice livestock to help researchers determine if a particular nonlethal LPT is effective?

While controlled experiments regarding the effectiveness of these tools may be next to impossible to conduct, there is a pressing need for more information amongst producers, land and wildlife managers, and conservation professionals. Objective analyses that account for the inherent differences in ranch management, environment, and surrounding land uses can help practitioners gain a better understanding about where these tools may be effective and, just as importantly, where they may not work.

LGDs are perhaps the most complex of these livestock protection tools to study. In addition to the variables described above, LGDs add complexity in the form of their own behaviors, their interactions with humans (handlers and strangers both), their interactions with predators, and their relationships with specific livestock, just to name a few. Research has generally shown that LGDs can be effective at reducing livestock losses due to predators (Coppinger et al. 1988; van Bommel and Johnson 2012; Scasta et al. 2017; Kinka and Young 2019), but questions remain about which behavioral, operational, and environmental variables may contribute to a specific LGD's success or failure. That information is critical for an individual producer when deciding whether LGDs may be effective on a particular operation. In addition, little LGD research has been conducted in California. Finally, LGD efficacy in protecting livestock other than sheep or goats is not well understood.

We are suggesting an objective framework for documenting the success or failure of LGDs in real-world settings over specific timeframes. We believe that by standardizing the collection and description of the many variables involved in a working ranch setting that impact LPT effectiveness, we can begin to build a more objective body of data regarding LGDs. We also believe that this framework could be used for other LPTs (like FoxLights™, electric fencing, fladry, and human presence). Finally, we believe that these case studies may provide livestock producers and others with information that will help them better assess the potential for using these tools in their own specific settings.

Variables That Impact LPT Effectiveness

The effectiveness of specific LPTs, including LGDs, can be impacted by numerous factors, such as environmental variables, the predator species present in an area, operational characteristics, and a producer's attitude and experience. Producers should take some or all of these factors into account when deciding not only whether an LGD will be a good fit for the operation in general, but also the number, type, and sexual status of LGDs that should be used.

Environment.—Terrain, type of vegetation (e.g., grassland versus brushland), surrounding land uses, and the LPTs used on surrounding landscapes can influence the success or failure of a particular tool. For example, a FoxLight™ that may effectively protect animals in a corral will not likely afford much protection in dense brush in a more extensive setting. When it comes to LGDs, environmental factors that affect sightlines, auditory and olfactory detection of predators, or ease of mobility may influence their success.

Predators present on the landscape.— While there is overlap between the types and ages of livestock threatened by different predator species, certain predators often target particular livestock more frequently than others. For example, coyotes attack sheep (*Ovis aries*) more often than do other predators (Larson et al. 2019; Scasta et al. 2017), though they also will prey upon goats (*Capra aegagrus hircus*) and calves (*Bovus taurus*) (Mitchell et al. 2004). Wolves are the predator species in California most likely to attack adult cattle, but they will also predate on calves, sheep, and goats (Scasta et al. 2017). The effectiveness of any LPT will vary depending upon the predator species present on an operation. Aerial predators, for example, won't be excluded by a fence. They also require LGDs to look up instead of only looking on the ground for threats. An individual LGD that is very effective against coyotes may not recognize common ravens (*Corvus corax*) or golden eagles (*Aquila chrysaetos*) as a threat.

Predation risk and the effectiveness of a given LPT will vary depending a variety of factors related to both predator and wild prey species. Predator seasonal diet preferences and spatio-temporal use of grazing areas will impact the likelihood of livestock depredation. Seasonal shifts in movements or diet of both predators and their wild prey can lead to varying predation risk throughout the year. An individual predator's sex, age, physiology, and behavior, among other factors, will all contribute to variability in predation risk and the effectiveness of different LPTs.

Operational characteristics.—Specific operational characteristics also likely influence the success or failure of a specific tool or suite of tools. Obviously, the species and class of livestock are related to susceptibility to predation events. Generally, beef cattle tend to be less susceptible to most predators than small ruminants (sheep and goats). However, even within a specific livestock species, the class of livestock can influence susceptibility (newborn calves are more susceptible than yearling steers, for example).

An individual operation's annual production calendar can also influence predation exposure. For example, some research suggests that a sheep operator who lambs during a time of year when the predators have ample natural prey may face less pressure from coyotes than a producer who lambs during a period when prey is scarce (Macon et al. 2018). Running dry females (cows, ewes, or does) in extensive settings without young (e.g., open-range sheep on Forest Service grazing allotments) may be less risky than grazing pairs (females with their young).

Human presence often varies between seasons and operations. Open-range sheep operations, for example, typically employ herders who have day-to-day responsibility for a band of sheep (1,000 to 1,200 head). These herders camp on the range and are with the livestock around the clock. Cattle producers who operate on similar extensive rangelands, on the other hand, typically do not employ herders or range riders. Livestock may be observed weekly or even less frequently during the grazing season. The decision to use human presence as a predator deterrent is complicated. Considerations include access to and affordability of skilled labor.

Isolating one particular LPT from all others is difficult because many producers use a suite of tools. The potential interplay between various tools further complicates one's ability to quantify the effect of a single tool. For example, one producer might use electronet fencing and LGDs, while a neighboring producer might use llamas and FoxLights™. Furthermore, the relationship between physical tools (e.g., fencing, fladry, alarms, etc.) and biological tools (LGDs, llamas, etc.) is not well understood.

Finally, producer attitudes and perspectives likely influence the long-term adoption of specific tools. A producer who thinks electric fence is expensive and unlikely to work during dry conditions will probably not adopt that tool. Similarly, a producer who believes LGDs are effective will be more likely to continue to use this tool even when problems arise.

The Case for Case Studies

In light of these challenges and uncontrollable variables, we propose a case study format that objectively describes the variables described above but also draws upon the experience of the producer, as highlighted in McInturff et al. 2019. This approach incorporates both sociological perspectives (such as producer perceptions) and ecological data to better inform management than assessing either in isolation. In our model, a case study describes the outcome of a real-world deployment of LGDs and allows other producers the necessary information to understand the potential similarities and differences between their operation and the one described in the case study so they can decide what tools may or may not be effective for their particular situation. Our approach includes examining LGD challenges and shortcomings to provide vital information on the potential limitations of a LPT instead of promoting a false sense of security. We hope to help spark new ideas or inspire producers to try a new tool or an existing LPT in a novel way.

METHODS

We conducted pilot-tested semi-structured questionnaire surveys of three livestock producers based in northern California. For the first case study, we examined a poultry operation in Marin County, which allowed us to examine the use of LGDs against aerial predators of poultry that were not effectively deterred by the other LPTs (electro-fencing and Foxlights™) utilized by the producer. The second and third case studies focused on sheep production in different settings in Placer and Nevada/Sierra Counties. In addition, we deployed camera traps on both sheep operations during the study period, allowing us to further examine local predator presence. We also interviewed the sheep herder who accompanied the sheep band in the third case study.

Case Study 1: Pastured Poultry Production in Marin County, California

Context.—While not as widely as discussed in the literature, LGDs are also used for poultry (*Gallus gallus domesticus*) production. We conducted a questionnaire survey of a free-range egg-laying chicken producer (who also runs Black Angus cows/calves) in the coastal region of northern California (in the general region of 38.093576, -122.828318). Our survey covered a study period of 12 months, from August 2019 through July 2020.

The operator purchased the LGDs to protect against bobcat, coyotes, and golden eagles (the biggest threats perceived by the producer), in addition to red-tailed hawks (*Buteo jamaicensis*) and the occasional long-tailed weasel (*Mustela frenata*). For bobcat, coyotes,

and golden eagles, the operator reported seeing or hearing the species or their sign on a daily basis. The producer noted that mountain lions had only been seen a handful of times over the years and never posed a threat to the livestock.

The operation had 4,500 chickens (commercial Production Reds) and 120 cows. The pastures were located on private land at around 90 m in elevation. The dominant habitats were grassland, riparian vegetation and marsh. The neighboring land was also private.

The producer owned four male LGDs (two pairs of siblings), and at the start of the study period one pair was two and a half years old and the other pair was one and a half years old. They were all Maremma x Great Pyrenees x Anatolian Shepherd crosses. One was neutered but the other three were intact, though the operator planned to neuter one more to reduce fighting between one of the sibling pairs. Each pair of sibling LGDs was kept together. The LGDs were purchased as puppies (8 to 10 weeks old) and were bonded to chickens under the producer's supervision. The adult size of the LGDs varied, with two siblings both weighing 45 kg and the individuals in the other pair weighing 54 and 38 kg. The producer had five years of experience with livestock guardian dogs.

Chickens were split between three pastures, and the two pairs of dogs were rotated among pastures. At any point in time, one group of chickens was without dogs. Shortly after the survey, the operator purchased two more LGD puppies to ensure each chicken flock would always be accompanied by a pair of LGDs. When the chickens were five weeks old, they were placed in the pastures with the LGDs. During calving season, which occurred August through September, some chickens and a pair of dogs were kept in the calving pasture to protect the calves from predators.

The chicken pastures were each one and a half to two acres in size. Most of the time, each pasture was surrounded by portable white electric net fencing. The typical grazing period per pasture was two weeks and chickens were never in the same pasture more than once in a year. The portable fencing was 122 cm tall and specifically made for poultry. It was erected for multiple purposes: to prevent chickens from wandering too far from the rest of the flock, to help exclude predators, to prevent the younger pair of dogs from roaming, and to make it easier to move chickens. The operator noted that the older pair of dogs would remain with the flock even without the presence of the electro fencing, but that was not the case for the younger pair.

In addition to the LGDs and electro fencing, the operation also deployed FoxLights™. Ideally, one was placed on every corner of each chicken pasture. During calving season, when the chickens were kept with the cows, the FoxLights™ were also placed at the corners of that pasture. The operator personally checked on the chickens at least three times per day and checked the calves (during calving season) once per day. The calves were kept in either traditional barb wire fencing or were on open range without a fence.

Results.— Over the 2019 calving season, three calves were lost to predators assumed to be coyotes, but the predator species was not confirmed. During the study period, one chicken was lost per month on average, compared with losing at least one to two chickens per day before using LGDs. During the times of year when there were more golden eagles in the area, the producer mentioned that it took a few days and a few losses for the LGDs to start actively protecting against the golden eagles.

Most chicken losses occurred in early morning, but some occurred midday. No chicken losses occurred at night, when chickens were inside mobile houses in the pasture. The producer attributed the fact that some losses were still occurring to the large number of

chickens that the LGDs needed to guard—they simply couldn't cover them all. There seemed to be more losses when the chickens were grazing closer to brush versus in an open field.

None of the LGDs roamed during the study period, though the operator attributed it to the fact that the younger pair of LGDs were kept inside the electro fencing. While the LGDs did occasionally come down to the ranch house to check out the ranch dogs, there never was a problem with the LGDs choosing to remain at the house instead of with the poultry. The dogs have never been aggressive towards people and as adults, the LGDs have never killed a chicken. The LGDs did have to be kenneled or tied up, however, whenever a border collie was used for gathering cattle, because the LGDs were aggressive towards that dog.

Over the last year, the operator witnessed the LGDs chase coyotes, but he never saw the LGDs catch or physically engage with them or any other predators. There were no known instances of the LGDs killing or injuring a wild animal or the LGDs being injured by wildlife. The LGDs were fed once per day, by hand because the chickens would steal the food if automatic feeders were used. The estimated total annual cost for the four dogs over the last year was between $1080 and $1540, including vet bills and food.

Overall for the last year, on a scale of one to five, the operator ranked LGD effectiveness as a four, because while the LGDs protected most of the livestock, they had not eliminated predation entirely.

Case Study 2: Pasture-based Sheep Production in Placer County, California

Context.—Flying Mule Sheep Company grazed approximately 100 head of sheep on foothill annual rangeland west of Auburn, California (38.96108, -121.18484), from mid-December through early April. The flock was comprised of bred ewes (approximately 80 head) and replacement yearling ewes (approximately 20 head). The grazed landscape was a large-lot subdivision (8.09 ha – 16.18 ha). Individual parcels were connected via paved and unpaved private roads and Nevada Irrigation District canals. Many residences had domestic dogs; some had horses and donkeys. Vegetation in the grazed landscape included open grasslands, blue/live oak savanna, blue/live oak woodland, and riparian vegetation. The terrain was rolling hills at approximately 243-305 m above sea level. Surrounding land uses included grazing land (cattle, sheep, and goats) and a large regional park (mostly wildland).

Twelve game cameras were placed throughout the grazed landscape in late December 2019. Cameras were placed adjacent to game trails, roads, and canals to help determine the species of wildlife present and the frequency of camera "capture" in relationship to the proximity of livestock guardian dogs and sheep. In order of decreasing prevalence in game cameras from late December through early April 2020, coyotes, foxes, bobcats, and a single mountain lion (in the evening on 1 March 2020) were noted. Other wildlife caught on camera included blacktail deer (*Odocoileus hemionus columbianus*), raccoons (*Procyon lotor*),striped skunks (*Mephitis mephitis*), jackrabbits (*Lepus californicus*), and wild turkeys (*Meleagris gallopavo*).

Sheep were mostly grazed in 107-cm electro-net paddocks ranging in size from 1.2 – 6.1 ha. Some paddocks incorporated a hard-wire sheep or deer field fence on one or more sides. Sheep were moved every 3 to 10 days. The flock was protected by one or two livestock guardian dogs. Bodie, a three and a half year-old Maremma x Anatolian intact male weighing approximately 41 kg), was with the flock for the entire period. In late March, a second dog was added (Elko, a two-year-old Great Pyrenees x Akbash intact male weighing approximately 50 kg). Both dogs were acquired as puppies between 8 and 12 weeks

of age and were bonded with sheep under the supervision of the producer. The dogs were fed daily, at which time sheep were checked as well (there was no around-the-clock herder with the flock). This producer has used livestock guardian dogs for 15 years, with varying degrees of success.

Results.—During the graze period (15 December 2019 through 6 April 2020), the producer had no predator losses. In early February, the producer found a buck that was likely killed by a mountain lion, buried in leaves and duff approximately 400 m from the camera that captured the lion photo. On the night that the game camera documented the mountain lion (1 March 2020), the flock was in a 5.3 ha paddock, the boundary of which was about 27 m southwest of the camera location. The south, east, and north sides of the paddock were 106.6-cm electronet fencing. The west fence was 1.8-m deer fence. On that date, there were 47 lambs with the ewes (between the ages of 1 and 11 days). The sheep had been moved into this paddock on the morning of 1 March 2020. Three lambs were lost during the time the sheep were in that paddock due to starvation or mis-mothering. There were no known instances of LGDs chasing or directly interacting with wildlife.

The producer reported that his current set of dogs didn't wander from their sheep, even if there were a failure in the electronet fencing. The dogs were not human-aggressive, accepted herding dogs if used by the producer, and could even be herded with the sheep to new paddocks. The sheep seemed inclined to follow the livestock guardian dogs if the dogs were led in front of the flock. The producer rated the effectiveness of his livestock guardian dogs as a five on a scale of one to five. The annual cost per dog (including feed costs, veterinary costs, and depreciation) was $367.

Case Study 3: Open-range Sheep Production on National Forest Land

Context.—Talbott Sheep Company grazed three bands of non-lactating (dry) ewes and rams on two grazing allotments on the Tahoe National Forest (39.497577/-120.1297558) between 9 July 2020, and 20 September 2020. Each band had at least one LGD with it and was managed by a herder, who camped with the sheep. Camps were moved every five to eight days to new bed grounds; sheep were taken to grazing areas and water in the early morning, bedded down near camp at mid-day, and taken back to grazing and water in mid-afternoon. The sheep were bedded near the camp at night. The operation was entirely open range; no fences (temporary or otherwise) were used. Each camp was supplied by a camp tender who assisted in moving camps and bands to new grazing areas.

The sheep bands were comprised of yearling and older ewes without lambs, along with approximately ten rams per band. Sheep were western whiteface (Rambioullet and Rambioullet-cross). Ewes weighed approximately 68-77 kg, while rams weighed approximately 113-136 kg.

For the questionnaire survey, we focused on the band that grazed from Kyburz Flat north of Stampede Reservoir down the east side of the Little Truckee River between Stampede and Boca Reservoirs. This band consisted of approximately 1200 sheep. The dogs were a three-year-old Great Pyrenees x Akbash cross male and a three-year-old Great Pyrenees male. The dogs were fed daily at the camp and roamed freely within the grazing area.

Rangeland types in the grazed landscape included sagebrush steppe, mountain meadows and associated riparian systems, and east side pine forest. The terrain was relatively flat to mountainous, ranging in elevation from 1,740 m above sea level to 1,950 m. Surrounding land uses included cattle grazing (on Forest Service and private lands) and heavy recreation

use (including developed and dispersed camping, off-highway vehicle use, boating, fishing, and hunting.

Twelve game cameras were placed throughout the grazed landscape for 70 trap days from early July to mid-September 2020. Cameras were placed adjacent to game trails to help determine the species of wildlife present and the frequency of camera "capture" in relationship to the proximity of livestock guardian dogs and sheep. Coyotes were the predator most frequently captured by the cameras, but some instances of bobcats were also recorded. Other wildlife caught on camera included mule deer (*Odocoileus hemionus*), golden-mantled ground squirrels *Callospermophilus lateralis*), jackrabbits (*Lepus californicus*), and sandhill cranes (*Grus Canadensis*).

In addition to interviewing the operator, we conducted a semi-structured interview with the herder on three occasions during the grazing season to determine the frequency of predator observations and to better understand predator impacts. The surveys were conducted via oral interviews in Spanish.

Results.—During the first two-week period that the band was grazing on the allotment, the herder reported the loss of a single ewe. He observed bear sign (tracks and scat) near the carcass and reported hearing bears frequently at night. Subsequent to that single event, no further predator conflicts were noted. A count of the band at load-out (20 September 2020) confirmed a single loss.

On 2 August 2020, the Great Pyrenees x Akbash cross LGD was picked up by a concerned citizen camping northeast of Stampede, who thought the dog was lost. The dog was taken to the animal control shelter in Truckee, California. The Talbott Sheep Company foreman retrieved the dog after paying a fine, and the dog was kept at the camp tender's camp near Hobart Mills for the remainder of the grazing season. From 2 August 2020 through 20 September 2020, this band was guarded by a single LGD, with no additional predator conflicts.

The producer reported that his dogs sometimes wander from their sheep, but typically not more than 800 m. The dogs were not human-aggressive and also accepted herding dogs used by the herder and other company staff. There were no known direct interactions between the LGDs and wildlife. The producer rated the effectiveness of his livestock guardian dogs as a five on a scale of one to five and the annual cost per dog was estimated at under $400.

DISCUSSION

Given the increasing need for implementing effective nonlethal livestock protection tools in California, information on how LPTs work in practice is vital. As has been shown elsewhere, the LGDs in these case studies promoted human-wildlife coexistence on both public and private lands. These three case studies exemplified the range of situations that LGDs can be implemented, from protecting poultry to sheep, working on public or private land, and in conjunction with a variety of other LPTs. Our approach explicitly addressed potential behavioral and situational challenges that producers should consider when making an informed decision on whether to use LGDs or not. While all three producers believed their LGDS had reduced livestock losses, in two of the three operations LGDs did not eliminate them entirely. Differences in individual LGD behavior, surrounding land use, and operation characteristics may contribute to unexpected challenges arising that are unrelated to the dogs themselves (e.g., recreationists "rescuing" an LGD assumed to be lost), yet still need to be considered.

Between producers recording sign and camera traps capturing predators, we were able to confirm that livestock on all three operations overlapped with predator species known to attack sheep, calves, and chickens. Despite the presence of LGDs and other LPTs, livestock losses weren't entirely eliminated in two of the three case studies, highlighting the difficulty in eliminating human-wildlife conflict for livestock producers. However, we cannot determine whether the predators recorded on the operations would have killed more livestock (rather than wildlife prey) if they had the opportunity, nor do we know if these predators took livestock from nearby unprotected herds or flocks during the study period.

Regardless of the complexities involved when examining LPTs in real-world settings, "Attempts to increase the involvement of these actors [producers, managers, and researchers], contributing together to evidence-based approaches, may be one way to alter the odds in a favourable direction. We are not suggesting that farmers or managers should do nothing until evidence is available, but merely encourage these actors to promote collaborative approaches, and work together in order to increase the proportion of studies aiming to quantify the effect of interventions." (Eklund et al. 2017). A continued compilation of case studies that apply our objective approach to the variables affecting LPTs and that span the wide spectrum of livestock operations in California will be critical for informing human-wildlife coexistence measures that benefit livestock, their producers, and wildlife.

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SUPPLEMENTARY MATERIAL

Questions—semi-structured interview

1. How many LGDs do you own?
2. What breed(s) are your LGD(s)? If a cross, please mention all breeds.
3. Is your dog(s) male or female?
4. How old is your LGD?
5. Is your LGD intact?
6. What type of livestock are with your LGDs?
7. What age classes of livestock are with your LGDs?
8. How many head of livestock are with your LGDs? If have multiple herds/flocks with different dogs, please clarify how many livestock are in each herd and how many LGDs each herd has. If "it depends," please describe your thought process as to how many dogs go with what herd.
9. How much does your dog(s) weigh?
10. What predators are you hoping your LGD(s) protects against?
11. How often do you see or hear those predator species or see fresh sign?
    ____ every day/night____ on a weekly basis ____ monthly____ never
12. How many years of experience do you have with LGDs?
    a. If have experience: How effective do you think your previous LGDs were at protecting your livestock? Did you ever have to rehome a LGD?
13. On a scale of 1-5, how effective do you think your LGD(s) is at protecting your livestock from predators?
14. Have you had any losses since you've been using LGDs? In the last year or grazing period?
    a. If yes: how many livestock, of what age class, and what predator was responsible? Please provide as much information as you can accurately remember—habitat (or do you remember the exact location)? Time of day? Why do you think the LGD did not protect against that loss? Did you change anything (including adding other protection tools) as a result of the loss?
    b. How often do you check for losses?

15. Did you have any losses before you got the LGD?
16. Do you have a herder with your livestock?
    a. If yes: are they with livestock during the day only or also at night?
17. What kind of setting do you have your livestock in?
    a. Hard wire fencing
    b. Electric fencing (permanent or mobile?)
    c. Open rangeland
    d. Other: please explain _____
18. Do you use any other nonlethal tools to protect your livestock? Pease describe.
19. Are you aware of any nonlethal tools being used to protect livestock on adjacent properties?
20. Have you noted any of the following problems with your LGD(s)? Check all that apply.
    - Roaming (how often? Has dog returned on its own or did someone find it and contact you?)
    - Remaining at house/barn instead of staying with stock (has this always been an issue? Or did it develop at a certain age?)
    - Chasing or harming livestock
    - Biting people
        i. Was the person a recreationist? Someone who works on your operation? Were they walking? Riding a bike? Please describe situation as best you can.
    - Fighting with other dogs in the operation
    - Have you noted any other problems not included on the list? Please describe. _____
21. What was the age of your LGD when you purchased it?
22. What costs have you incurred over the lifetime of your LGD?
23. Do you have insurance to cover potential liabilities for your LGD?
24. What type of land do you graze your livestock? (public, private?)
25. What's the dominant habitat type(s) in the areas where you graze your livestock?
26. If a cattle producer, when is your calving season? And what breed(s) of cattle do you have?
27. Have you ever witnessed your LGD physically engage with a predator? What happened?
28. As far as you are aware, has your LGD ever killed or injured a wild animal?
29. Has your LGD ever been injured by a wild animal?

Conflict Hotspots & Mitigation

Conflict Hotspots & Mitigation

Photos, previous page:

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1. Tule elk (*Cervus canadensis nannodes*) standing at alert in natural habitat. Photo Credit: California Department of Fish and Wildlife
2. Black bear in the Sierra Madre Mountains, California. Photo Credit: Johanna Turner, Cougar Conservancy
3. California condors (*Gymnogyps californianus*) perched on a deck in the Tehachapi Mountains, California. Photo Credit: California Department of Fish and Wildlife
4. Mule deer (*Odocoileus hemionus*) bucks with antlers interlocked and entangled in a barbwire fence. Photo Credit: California Department of Fish and Wildlife
5. Barn owl (*Tyto alba*) carrying small prey while in flight. Photo Credit: California Department of Fish and Wildlife
6. Black bear damage (*Ursus americanus*) caused by attempting to access bee hives protected by an electrified fence. Photo Credit: Dennis Moyles, Siskiyou County Department of Agriculture

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FULL RESEARCH ARTICLE

Thematic and hotspot analysis of human-elk conflicts statewide in California

KRISTIN DENRYTER[1, 3]* AND ALEX HEEREN[2]

[1] *California Department of Fish and Wildlife, Elk and Pronghorn Program, Wildlife Branch, 1010 Riverside Parkway, West Sacramento, CA 95606 USA (Former)*

[2] *California Department of Fish and Wildlife, Human Dimensions of Wildlife Unit, Wildlife Investigations Lab, 1701 Nimbus Road, Rancho Cordova, CA 95670 USA*

[3]*Alaska Department of Fish and Game, Wildlife Nutrition Lab 1800 Glenn Hwy #2, Palmer, AK 99645 (Present)*

**Corresponding Author: Kristin.Denryter@alaska.gov*

Human-wildlife conflicts are an important factor for consideration in wildlife management at urban-wildland interfaces. Effective and adaptive management of human-wildlife conflicts is needed to promote tolerance and coexistence of humans and wildlife. Anecdotal reports suggest a recent spike in human-elk conflicts in California, yet there has not been a systematic analysis of human-elk conflicts in the state. To better understand human-elk conflicts in California, we conducted thematic analysis of human-elk conflicts reported in the California Department of Fish and Wildlife's *Wildlife Incident Reporting* (WIR) system. We also conducted a hotspot analysis using locations of human-elk conflicts reported in the WIR system and evaluated reports for principles of adaptive management. The WIR system contained n = 89 reports for elk and n = 78 of these described conflicts with elk. Overall, property damage (including crop damage) was the most common type of human-elk conflict reported, occurring in 69% of reports (n = 54/78), followed by non-competitive conflict with domestic animals (13%), competition with domestic livestock (12%), and habituation to humans (24%). We identified three hotspots of human-elk conflict in California in Del Norte, Kern, and San Luis Obispo counties. All incidents of human-elk conflict reported in the WIR system included at least one principle of adaptive management. We recommend modifications to the WIR system and interactions with property owners and stakeholders to enhance and facilitate adaptive management of human-elk conflicts in California.

Key words: adaptive management, *Cervus canadensis*, conflict transformation, crop damage, depredation, fence damage, forage competition, property damage

Conflicts between humans and wildlife are an important aspect of wildlife conservation and management, particularly in areas where expansive urban-wildland interfaces exist. Human-wildlife conflicts at urban-wildland interfaces can range from mild nuisance (e.g., deer eating a flower or vegetable garden; Drake et al. 2005) to monetary losses from crop or domestic animal depredation (Madhusudan 2003; Mackenzie and Ahabyona 2012) and destructive property damage (e.g., bears breaking into vehicles and buildings; Madison 2008). Human-wildlife conflicts can undermine species conservation efforts (Inskip and Zimmermann 2009; Mateo-Tomás et al. 2012) and can impact public support for conservation and management policies (Redpath et al. 2004; Madden and McQuinn 2014). Therefore, conflict transformation (Madden and McQuinn 2014) is critical in managing and conserving wildlife at the urban-wildland interface.

Previous studies of human-wildlife conflict often have focused on social tolerance of large carnivores (e.g., Treves et al. 2004; Madison 2008; Bruskotter et al. 2009; Slagle et al. 2013; Bruskotter and Wilson 2014; Bautista et al. 2017). Large herbivores, such as deer (*Odocoileus* spp.) and elk (*Cervus canadensis*), also can be a significant source of human-wildlife conflict (Van Tassell et al. 2000; Lee and Miller 2003; Walter et al. 2010). Herbivorous species can cause "depredation" (i.e., property damage or destruction, consistent with California Fish and Game Code section 4181) when they consume agricultural crops or cause damage to trees, shrubs, fences, or buildings (VerCauteren et al. 2006; Hegel et al. 2009; Walter et al. 2010). Large herbivores also can pose a risk to human health and safety through vehicle collisions (Gagnon et al. 2007) and as vectors of zoonotic disease (Michalak et al. 1998; Rhyan et al. 2013). In recent years, the need to better understand conflicts between humans and elk was identified as one objective in California's Elk Conservation and Management Plan, hereafter the California Elk Plan (California Department of Fish and Wildlife (CDFW) 2018). The California Elk Plan calls for alleviation of human-elk conflict and emphasizes growing elk populations by 10% where conflict is expected to be minimal (CDFW 2018). To know where conflict is expected to be minimal, first it is necessary to understand what constitutes human-elk conflict in California. While anecdotal reports suggest elk conflicts in California are largely related to depredation, including property damage, a more robust and systematic approach is needed to quantitatively assess conflict and meet goals identified in the California Elk Plan. Establishing a baseline of conflicts from data also is necessary to map "hotspots" of human-elk conflicts, which also was identified as a need in the California Elk Plan.

The California Elk Plan also emphasizes the importance of adaptive management, which is a structured, iterative process used to make, evaluate, and learn from management decisions with the overall goal of improving management and decreasing uncertainty over time (Stankey et al. 2005; Williams et al. 2009; Williams 2011). Although definitions and structures for adaptive management vary, they typically involve the following elements, structured in an iterative process: (1) conceptualizing the problem, (2) planning monitoring and other actions, (3) implementing planned actions, (4) analyzing and interpreting results, and (5) adapting strategies based on results. Understanding what human-elk conflict is occurring, and where it is occurring in the state, is central to conceptualizing the scope of the problem and is a necessary first step in the adaptive management process.

To support goals for elk conservation and management identified in the California Elk Plan (CDFW 2018), we systematically reviewed reports of human-elk conflict submitted to the California Department of Fish and Wildlife (CDFW). Our objectives were to: (1) describe

predominant themes of human-elk conflict in California; (2) map hotspots of human-elk conflicts throughout California; (3) and evaluate whether responses to human-elk conflict were consistent with principles of adaptive management. We also identified other potential sources of human-elk conflict not reported in the WIR system, future research priorities, and provided recommendations to enhance management and resolution of human-elk conflicts in California.

METHODS

Study Area

California is home to three subspecies of elk—Rocky Mountain (*Cervus canadensis nelsoni*), Roosevelt (*C. c. roosevelti*), and tule (*C. c. nannodes*; endemic only to California) that are distributed throughout 22 Elk Management Units (EMUs; Fig. 1). Though once

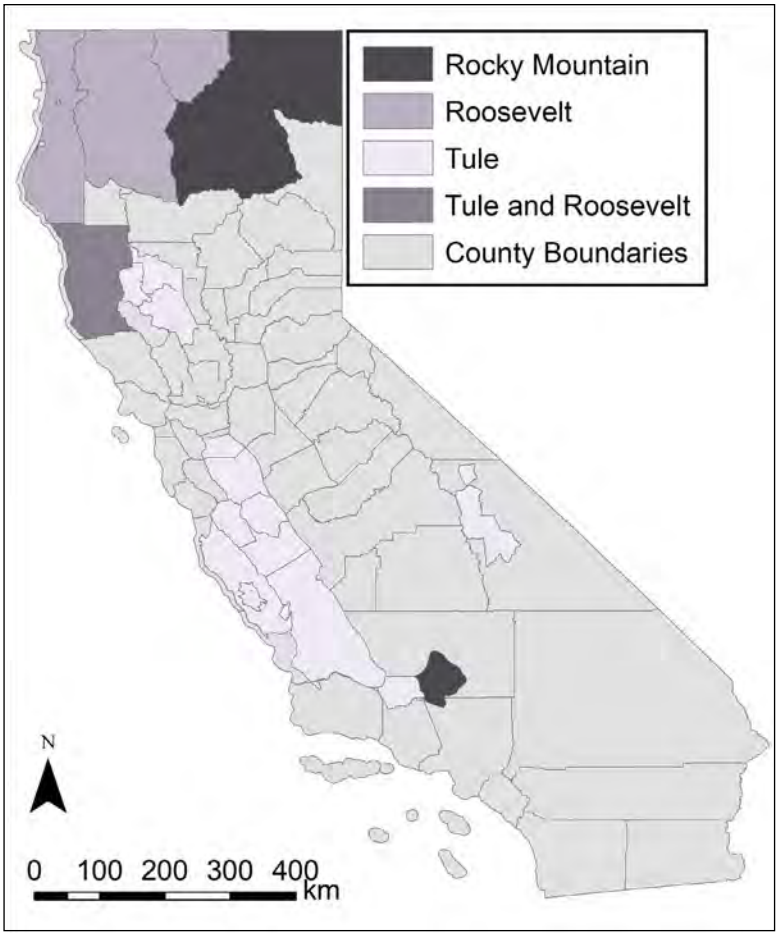

Figure 1. Distribution of Rocky Mountain, Roosevelt, and tule elk in 22 elk management units in California (current as of December 2020; locations of confined herds are not shown).

decimated throughout California—and in some cases pushed to the brink of extinction (tule elk) or extirpation (Roosevelt elk)—all three subspecies of elk in California are increasing in number and distribution throughout the state (CDFW 2018).

Roosevelt elk in California occur primarily in the North Coast and Klamath Province, from coastal Mendocino County north to Humboldt and Del Norte counties, as well as part of Shasta, Trinity, Tehama, and Siskiyou counties. Roosevelt elk use various types of habitats including montane and bottomland grasslands, oak woodlands, coastal dunes, coastal coniferous rainforests, and wetlands. Predominant tree species are hemlock (*Tsuga heterophylla*), grand fir (*Abies grandis*), Douglas fir (*Pseudotsuga menziesii*), chinquapin (*Chrysolepsis chrysophylla*), noble fir (*Abies procera*), white fir (*Abies concolor*), and red fir (*Abies magnifica*). Coastal habitats are characterized by mild temperatures and substantial rainfall, whereas more interior areas experience rain-shadow effects and extreme temperatures. Elevation ranges from approximately 0–4200 m. Land ownership varies among each Elk Management Unit occupied by Roosevelt elk: 80% of land in the Mendocino Roosevelt Elk Management Unit is privately owned, compared to 40% and 35% of land in the North Coast and Marble Mountains EMUs being privately owned (CDFW 2018). Primary land uses on private lands include forestry, livestock operations (e.g., dairy farming, ranching), and commercial crop production (e.g., lilies, pumpkins).

Rocky Mountain elk occur primarily in northeastern California in the Cascades and Modoc Plateau province in Modoc, Siskiyou, Lassen, Plumas, Butte, and Shasta counties. Habitat types available to Rocky Mountain elk in northeastern California include blue oak (*Quercus douglasii*)-foothill pine (*Pinus sabiniana*), Sierran mixed conifer, montane hardwood-conifer, Ponderosa pine (*Pinus ponderosa*), and montane hardwood. Elevation ranges from 240–3,000 m (CDFW 2018). Predominant tree species include lodgepole pine (*Pinus contorta*), western white pine, ponderosa pine (*Pinus monticola*), white fir (*Abies concolor*), and aspen (*Populus tremuloides*: CDFW 2018). Land ownership is approximately 55% public and predominant land uses on private lands include forestry, livestock operations, and agricultural crop production. Another population of Rocky Mountain elk occurs in in Kern County, in central California—part of the Central Valley and Sierra Nevada Province (CDFW 2018). In the 1960s, a local ranch operator imported Rocky Mountain elk to the area from Yellowstone National Park; poor fence maintenance on the ranch resulted in elk escaping confinement and establishing a free-ranging population (CDFW 2018). Rocky Mountain elk in Kern County use habitats ranging in elevation from 900–2,400 m (CDFW 2018). Land ownership is primarily private within the EMU, and land is used for farming and livestock grazing (CDFW 2018). As of 2018, private property conflicts were considered minor (CDFW 2018). Additionally, there are Rocky Mountain elk on a private ranch on California's Central Coast, in San Luis Obispo County.

Tule elk have the broadest distribution of all three subspecies of elk in California, occurring in the North Coast and Klamath (Mendocino County), Bay Delta and Central Coast (Solano, Marin, Alameda, San Joaquin, Santa Clara, parts of Stanislaus, Monterey, and San Luis Obispo counties), Central Valley and Sierra Nevada (Lake, Colusa, Glenn, Yolo, parts of Stanislaus, Merced, and Kern counties), and Deserts provinces in California (Owens Valley, Inyo County). Predominant habitat types in the Bay Delta and Central Coast Province include estuarine marshes (e.g., at Grizzly Island Wildlife Area); annual grasslands; blue oak, interior live oak (*Quercus wislizeni*), and mixed oak-foothill pine woodlands; mixed chapparal, and riparian (CDFW 2018). Common wetland plants in estuarine marshes include

saltgrass (*Distichlis spicata*), pickleweed (*Salicornia virginica*), tules (*Scirpus* spp.), cattails (*Typha* spp.), Baltic rush (*Juncus balticus*), and fat hen (*Atriplex triangularis*). Grassland plants include brome (*Bromus* spp.), wild oats (*Avena* spp.), fescues (*Festuca* spp.), ryes (*Lolium* spp.), tall wheatgrass (*Elytrigia* spp.), and mustards (*Brassica* spp.; CDFW 2018). Habitat types in the Central Valley and Sierra Nevada province includes annual and perennial grasslands, mixed chaparral, blue oak woodlands, blue oak-foothill pine, valley oak (*Quercus lobata*) woodlands, coastal chapparal (CDFW 2018). Elevation ranges from 0–2,700 m. Up to 90% of lands in some EMUs in the Central Valley and Sierra Nevada and Bay Delta and Central Coast provinces are privately owned and these areas are the most densely populated within the range of tule elk (CDFW 2018). Primary land uses include residential and commercial developments, agricultural crop production, and livestock grazing. The climate is Mediterranean and characterized by hot, dry summer, and cool, moist winters (CDFW 2018). Oak, pine, chamise (*Adenostoma fasciculatum*) and Ceanothus (*Ceanothus* spp.) comprise the predominant trees and shrubs (CDFW 2018). In the Desert province, habitat types are primarily Great Basin and Mojave Desert shrub communities, with predominant species of vegetation varying across elevational and moisture gradients, including saltbush (*Atriplex* spp.), sagebrush (*Artemisia* spp.), rabbitbrush (*Chrysothamnus nauseosum*), greasewood (*Sarcobatus vermiculatus*), saltgrass (*Distichlis spicata*), shadescale (*Atriplex confertifolia*), bitterbrush (*Purshia* spp.), mountain mahogany (*Cercocarpus ledifolius*) and Ceanothus (CDFW 2018). In riparian areas, willows (*Salix* spp.), cottonwood (*Populus fremonti*), and cattails (*Typha domingensis*) predominate and >95% of land ownership is public, with the Los Angeles Department of Water and Power being the primary landowner in the Owens Valley (CDFW 2018). Additional information on geophysical and ecological descriptions of California's ecological provinces and habitat types available to elk is provided in the California State Wildlife Action Plan (CDFW 2015) and the California Elk Plan (CDFW 2018).

Data Collection and Analyses

To identify major categories of human-elk conflict and conflict hotspots in California, we queried CDFW's *Wildlife Incident Reporting* (WIR) system for all entries on elk. Since 2016, the California Department of Fish and Wildlife has used the WIR system to track and respond to human-wildlife conflicts; depredation permits and reports from years prior to 2016 are being migrated into the WIR system. Any member of the public can report incidents through the Department's public web page for the WIR system (https://apps.wildlife.ca.gov/WIR/). The reporting party (RP) enters information about the incident, including species, date, type of incident (e.g., concern for animal welfare, depredation, general nuisance, mortality, potential human conflict, sighting, and public safety). Based on the location of the incident, the WIR system automatically assigns a CDFW investigator (either a biologist or a wildlife officer) who reviews the report and determines what action, if any, is appropriate. The investigator may conduct an investigation and provide advice on mitigation measures, or in some cases, may issue a depredation permit to the RP. While not all reports of conflict go through the WIR system (some calls go directly to CDFW staff in regional offices), it is the only centralized database of conflict incidents available to CDFW staff statewide.

After querying the WIR system for all reported elk incidents, we conducted a thematic analysis, using an inductive and semantic approach (Braun and Clarke 2006). That is, we allowed the data to determine themes and analyzed explicit content of WIR reports, rather than coming to the data with predetermined themes and reading into subtext and assump-

tions motivating responses. We familiarized ourselves with the data and then identified and coded themes from the data, first at relatively coarse scales and then used secondary codes to describe subthemes within the data.

To map hotspots of human conflict, we overlaid locations of conflict (excluding reports categorized as 'sightings'). Incident data were aggregated by counting incidents within fishnet polygons using the Optimized Hot Spot Analysis tool in ArcMap 10.4 (Environmental Systems Research Institute, Redlands, CA). We conducted the analysis at the statewide level to ensure adequate sample sizes (i.e., a minimum of 30 points per polygon are required for hotspot analyses in ArcMap).

Finally, we evaluated whether departmental responses to conflict were consistent with the five principles of adaptive management (1) conceptualize (and defining) the problem, (2) plan monitoring and other actions, (3) implement planned actions, (4) analyze and interpret results, and (5) adapt strategies based on results. We evaluated language and content of reports for evidence of principles of adaptive management as follows. If incident reports described the incident type explicitly (e.g., RP categorized incident as depredation) or the incident type could be inferred from language used in the description (e.g., elk attacking livestock), reports were considered to meet principle 1. If incident reports or responses included a description of plans for monitoring, they were considered to meet principle 2. Principles 3 and 4 were considered met if information was provided on how monitoring plans and actions were implemented, including any outcomes related to these plans and actions. We considered principle 5 met if responses were adapted based on results and outcomes associated with principle 3 and 4.

RESULTS

The *Wildlife Incident Reporting* system contained n = 89 reports for elk reported between 3 Nov 2009 and 4 Oct 2020 (Fig. 2, 3). These included n = 62 (70%) reports categorized as depredation by elk, n = 11 (12%) reports categorized as general nuisance by elk, n = 7 (8%) reports categorized as potential human conflicts with elk, and n = 9 (10%) reports categorized as sightings of elk (Fig. 4). Incidents were reported in 12 counties (Figs. 3, 4). Reports characterized as sightings and those related to concerns over animal welfare were excluded from analyses as they did not constitute human-elk conflict. For reports describing human-elk conflict (n = 78), we identified four predominant themes: (1) property damage (including crop damage), (2) injury or harm to domestic animals, (3) competition with domestic livestock, and (4) habituation to humans. Many reports (n = 27) described conflicts related to more than one of the predominant themes or multiple incidents per subtheme (e.g., multiple crops reported damaged).

Property damage was the most common type of conflict with elk reported in the WIR system, occurring in 69% (n = 54) of reports a total of n = 85 times. Fence damage was the most frequently reported subtheme of property damage (n = 32), followed by crop damage (n = 27), damage to landscape or landscaping (n = 9), damage to orchards (n = 9), and damage to vineyards (n = 5). Reports of crop damage included eating crops, trampling crops, and defecating in crops. Affected crops included lettuce, lilies, alfalfa, corn, cauliflower, broccoli, green onion, and green chard, however, not all reports specified a type of crop damaged. Fruit (e.g., apple, plum) and nut (e.g., almond) trees were damaged by elk rubbing antlers and stripping bark from trees. Landscape damage included damage to lilacs (n = 1), tropical flowers (n = 1), gardens (including vegetables; n = 3), and other non-specific

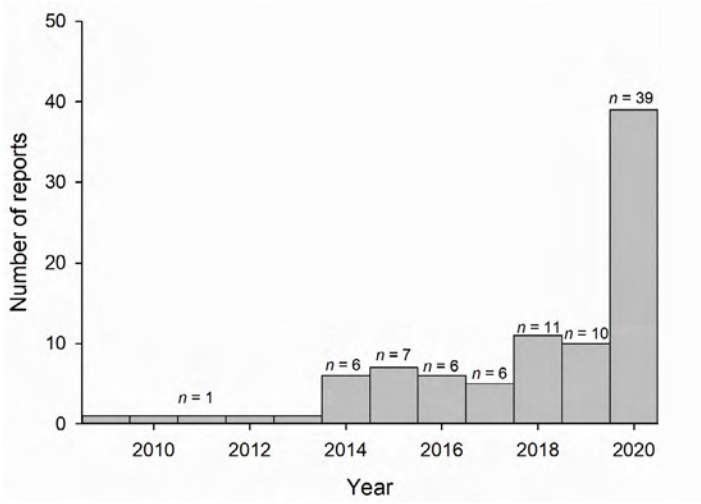

Figure 2. Number of reports concerning elk, by year, in the *Wildlife Incident Reporting* (WIR) system in California from 4 Nov 2009–4 Oct 2020.

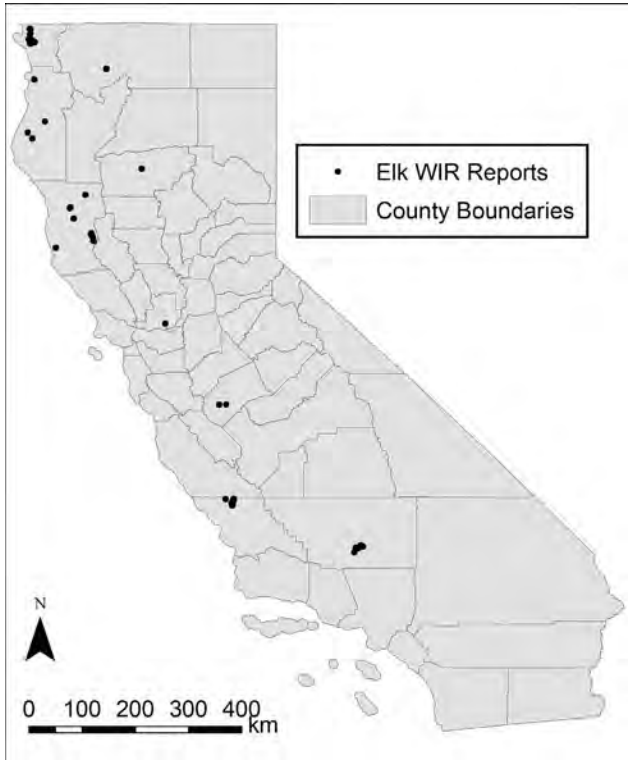

Figure 3. Locations of all *Wildlife Incident Reporting* (WIR) system reports concerning elk throughout California from 4 Nov 2009–4 Oct 2020.

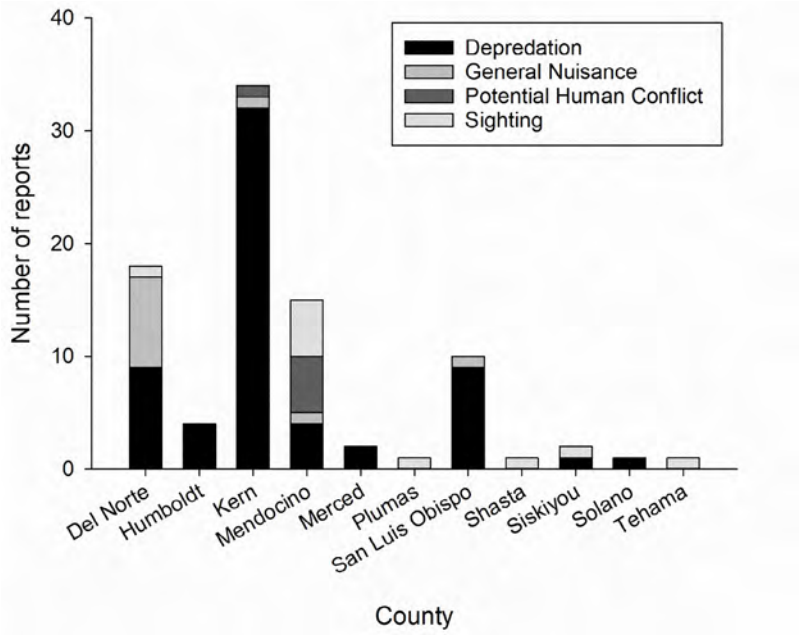

Figure 4. Number of *Wildlife Incident Reporting* (WIR) system reports concerning elk, by report category, from 4 Nov 2009–4 Oct 2020.

damage (e.g., damage to "field", "shrubs", "bushes"). Other reports of property damage mentioned damage to tractors, game cameras, antennas, and metal trash cans. Incidents of conflicts between elk and domestic animals were described in n = 19 reports, including incidents described as competition with domestic livestock (n = 9; 12% of all conflict reports) and non-competitive conflicts with domestic animals (n = 10; 13% of all conflict reports). Competition with domestic livestock included n = 8 reports of elk consuming pasture or forages (e.g., grass, hay) and animal feed and one report suggested elk were competing with livestock for water. Non-competitive conflicts included n = 7 reports of elk harassing or injuring domestic animals. Male elk were reported to stomp cattle calves and injure or break calves' legs (n = 2). One report described an elk attacking and severely injuring a dachshund (small breed dog). Another report described a dog barking at elk and then being kicked by a female elk. Three other reports included reports of elk chasing pets, harassing horses, or safety concerns of elk endangering children. Livestock also were reported missing after elk damaged fences (n = 3).

Habituation (e.g., a lack of wariness or fear, failure to disperse) to humans was described in 24% of all conflict reports. In most (17 out of 19 reports), habituation was reported with concerns about depredation, not as a stand-alone incident. The two stand-alone reports of habituation described an elk approaching or not moving away from a highly trafficked hiking trail and a concern that an elk was nearby (however, no aggression was described). Efforts to haze elk were described in n = 17 reports of property damage, with habituation to humans (including hazing activities) described in n = 16 reports. Elk were described as

unafraid of people, vehicles, loud noises (e.g., gunshots, noisemakers), lights, being hit with rubber bullets, or if they were deterred, they sometimes returned within minutes to hours after deterrence was suspended.

We identified three hotspots of human-elk conflict in California using n = 78 locations of human-elk conflict reported throughout California in hotspot analysis at the 99% confidence level. Human-elk conflict hotspots occurred in Del Norte, Kern, and San Luis Obispo counties, with the latter conflict hotspot extending into Monterey County (Fig. 5). All areas outside of the three identified conflict areas were determined to be non-significant in the hotspot analysis.

Among WIR system reports, n = 89 conceptualized the problem (principle 1 of adaptive management). Actions by CDFW were reported for n = 72 incidents, but few included substantive detail regarding specific responses; systematic monitoring (principle 2) was not planned as part of any responses. The most common action by CDFW was to advise (or attempt to advise—outreach with no response) the RP (n = 65) on actions that could be implemented, but only n = 1 incident mentioned continued communication (i.e., monitoring) between the RP and CDFW regarding the conflict. Except for reports of elk taken under

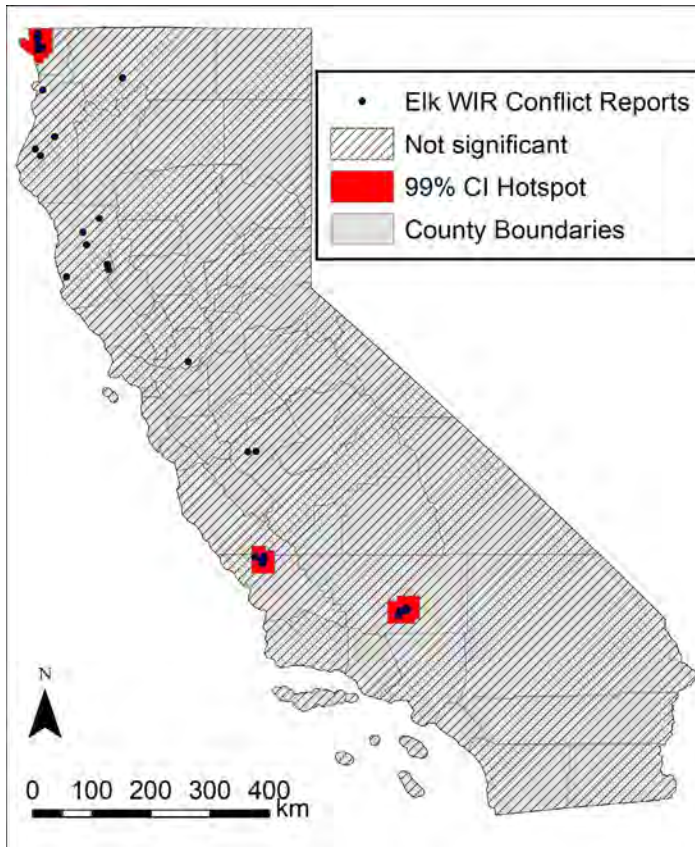

Figure 5. Hotspots of human-elk conflict in California from 4 Nov 2009–4 Oct 2020, shown as 99% confidence intervals (CIs) of hotspots (red), identified using Optimized Hot Spot Analysis in ArcMap 10.4. All areas outside of 99% CIs were not significant in the Optimized Hot Spot Analysis.

two of four lethal depredation permits that were issued, incident reports did not include follow up regarding whether planned actions were implemented (principle 3) or the results of implementing actions (principle 4).

DISCUSSION

Human-wildlife conflicts are on the rise where urban-wildland interfaces exist (e.g., Schell et al. 2020) and human-elk conflicts in California are no exception. Human-elk conflicts have increased in recent years (Fig. 2) concurrent with increases in distributions, numbers, and densities of elk throughout California (CDFW 2018). Using reports of human-elk conflict in CDFW's *Wildlife Incident Reporting* system, we identified four predominant themes of human-elk conflict in California, including property damage, conflicts with domestic animals, and habituation to humans. We also mapped three hotspots of human-elk conflict in California. Our analyses also suggested that principles of adaptive management were weakly or incompletely applied in CDFW responses to human-elk conflicts.

Property damage was the predominant type of human-elk conflict in California as reported in the WIR system and fence damage caused by elk was a major subtheme documented almost universally throughout reports from across the state. Fence damage often was attributed to elk not clearing top wires of fences while trying to jump over them. As such, damage to fences caused by elk passage may be alleviated by modifying fencing to facilitate crossing (Hanophy 2009) where total exclusion of elk is not necessary or practical. Where total exclusion of elk is desired (e.g., because of conflicts related to forage competition or crop depredation), game-proof fences, including woven-wire and electric fences (e.g., CDFW 2018), may be the most effective option; however, such fences may not be economically feasible. Future research is needed to better understand what type of exclosures are feasible for most property owners.

Fencing and exclosures cannot alleviate all health and safety concerns related to disease outbreaks. For example, recent outbreaks of *Escherichia coli* in leafy greens have occasionally been linked to contamination from cattle in pastures upslope from greens fields (USFDA 2020), but we do not know of any outbreaks that have been attributed to elk in California (however, elk can transmit *E. coli* pathogens; Franklin et al. 2013). Where consumption of crops by elk is the primary conflict, new deterrence methods, including use of tannins or polyrope electric fences may help alleviate conflicts with elk while maintaining safe and marketable commercial produce (Johnson et al. 2014, Monteith et al. 2019). Tannins, however, would not be useful to alleviate competition with cattle for forage, as cattle, like elk, are ruminants, and tannins impede digestion in ruminants (Robbins et al. 1987a, b). Future research also can help determine how aware landowners are of alternatives to exclusion fencing, and how awareness and implementations of such methods can be increased. Fencing also may be contraindicated when maintaining landscape connectivity is a management or conservation goal (Woodroffe et al. 2014). The California Department of Fish and Wildlife should continue to work with landowners and encourage implementation of fence-modifications that may alleviate conflict where total exclusion is not needed. In some situations, fence modifications could be trialed as part of an adaptive management response, particularly where private landowners, non-governmental organizations, CDFW, and other partners (e.g., Tribes, federal agencies) can work together to implement fence modifications and monitor their efficacy in alleviating human-elk conflict.

Based on conflicts reported in the WIR system, we identified three hotspots of conflict in California, centered in Del Norte, San Luis Obispo, and Kern counties. The three hotspots of elk hotspots aligned with perceptions of where there are high levels of human-elk conflict in California (as indicated by anecdotal reports from regional CDFW staff; A. Gwinn, D. Hacker, C. Hilson, personal communications; and comments during public meetings). Several other areas we expected to be hotspots of conflict were not significant in the hotspot analysis. For example, anecdotally, human-elk conflicts are on the rise in Mendocino County (Moran et al. 2020), including several conflicts reported in the WIR system (Figs. 3, 4), yet Mendocino County was not identified as a conflict hotspot (Fig. 5). Similarly, human-elk conflicts have been reported anecdotally in Monterey and Inyo counties (J. Cann and M. Morrison, California Department of Fish and Wildlife, personal communications; CDFW 2018), but there were no reports of elk conflict in the WIR system for Monterey or Inyo counties. The relatively fewer hotspots than anticipated likely reflects a lack of reporting in the WIR system, rather than a lack of elk conflict in places like Mendocino and Inyo counties.

Public outreach, education, and communication could help spread awareness of the WIR system as a tool and resource in managing human-elk conflict. If more landowners are aware of the WIR system and how to communicate with CDFW about human-elk conflict, the WIR system will become a more reliable and valuable research tool for mapping conflict. Additional information on conflicts could help refine hotspot analyses, which ultimately could support regulatory changes aimed at alleviating human-elk conflicts. In identified conflict hotspots, as well as potential conflict hotspots (e.g., Inyo, Mendocino, Monterey counties), comprehensive population and conflict monitoring is essential for alleviating conflict, which is a primary goal of the California Elk Plan (CDFW 2018). In conflict hotspots, human dimensions research also may help with conflict mitigation or transformation, particularly relative to defining tolerable levels of conflict that can facilitate coexistence between humans and elk (Mekonen 2020).

Some RPs requested compensation for losses associated with fence damage, forage or crop depredation, or crop abandonment (due to potential health safety concerns). While some states (e.g., Colorado, Idaho, Montana) have programs to compensate landowners for depredation by wildlife, California has no such program. Compensation programs have documented mixed success (Wagner et al. 1997) and can have unintended consequences, including exacerbation of conflict (Bulte and Rondeau 2005). An alternative to compensation, and in some cases fencing, available to some landowners is enrollment in the CDFW Shared Habitat Alliance for Recreational Enhancement (SHARE) program. The SHARE program generates revenues through applications for hunting tags, which are issued for specific properties, thereby allowing hunting to reduce or disperse elk from conflict areas, while also incentivizing tolerance for elk on private lands (C. Hilson and V. Barr, California Department of Fish and Wildlife, personal communication). Anecdotally the SHARE program has been considered at least moderately successful in at least one conflict hotspot (i.e., Del Norte County) and hunting as a management tool for ungulate conflicts has been successful elsewhere (e.g., Shaw 1995; Walter et al. 2010). More work is needed to systematically evaluate the success of the SHARE program in alleviating human-elk conflict and promoting elk tolerance and coexistence between elk and humans.

Several types of human-elk interactions that we expected to see reported in the WIR system were notably absent, despite being potentially important sources of human-elk conflict, including elk-vehicle strikes and several zoonotic disease occurrences. This lack

of reports on zoonotic disease and elk-vehicle strikes is likely due to the limits of the WIR system as a reporting tool rather than absence of those types of conflicts. For example, elk-vehicle strikes are generally reported to the California Roadkill Observation System administered by the Road Ecology Center at the University of California Davis (Waetjen and Shilling 2017). Wildlife health and disease concerns may be directly reported to CDFW staff in regional offices or the Wildlife Investigations Laboratory. Treponeme-associated hoof disease (TAHD) was first documented in Roosevelt elk in Del Norte County in April 2020 (Munk et al. 2020), and there is concern over whether it is transmissible between livestock and elk; yet there are no reports of elk with signs of TAHD in the WIR system. Similarly, there were no reports for concerns over Johne's disease, which is transmissible between cattle and elk, and is a source of conflict at Point Reyes National Seashore in northern California (Manning et al. 2003).

All WIR reports met at least one principle of adaptive management—conceptualizing the problem (Stankey et al. 2005; Williams et al. 2009; Williams 2011). Conceptualizing the problem is built into the framework of the WIR system as RPs must select a category for their report and then may write a longer description of the incident, which allows for further qualitative analysis. Many incidents described in the WIR reported CDFW staff advising RPs about potential actions to alleviate conflict (principle 2 of adaptive management). Some RPs described their implementation of actions (principle 3), as well as perceived outcomes of those actions (principle 4), and requested strategies be adapted based on their perceptions (principle 5). Generally, RPs reported hazing efforts that failed to keep elk away for extended periods of time, perceiving hazing efforts as a failure and using those observations to support requests for lethal depredation permits. Hazing may need to be ongoing to be successful (Walter et al. 2010); cessation of hazing undoubtedly can result in animals returning to an area, particularly if desirable resources are available.

The WIR system is focused on alerting CDFW to conflict and serving as a format for the RP to communicate concerns to CDFW. In this sense, it is largely a reactive tool and has limited utility to proactive or preventive management of conflict. Nevertheless, adaptive outcomes were proposed by CDFW in response to n = 32 incidents of human-elk conflict in the WIR system. For example, changes to hunt-zone boundaries in San Luis and Kern counties represented an adaptive response to human-elk conflicts and were suggested because other methods for conflict alleviation had apparently failed (K. Denryter, personal observation). Similarly, in response to increasing elk conflicts in the North Coast EMU (which includes the third conflict hotspot of Del Norte County), hunting tag numbers were increased to help alleviate human-elk conflicts by reducing elk numbers, dispersing elk, and by enrolling landowners in the SHARE program (K. Denryter, personal observation).

To increase transparency and adherence to an adaptive management model for human-elk conflicts, we recommend several enhancements to CDFW responses to human-elk conflicts and the WIR system. First, we recommend CDFW staff responding to human-elk conflict work more closely with reporting parties to outline a plan of action and monitoring. Specific actions intended to alleviate human-elk conflicts should be identified and implemented and responses should be systematically measured through monitoring (principles 2 and 3 of adaptive management). The action and monitoring plan should identify what responses will be measured and at what scale—information necessary to evaluate the efficacy of actions (principle 4 of adaptive management). For example, if hazing is recommended, the type, frequency, intensity (e.g., number of humans involved in hazing, human-hours of

effort), and duration of hazing activities should be specified. Information on responses of elk to hazing, such as distance moved, amount of time between elk leaving and returning to the property following hazing, group size (before and after hazing), etc. also should be collected and analyzed to evaluate the efficacy of various actions in response to human-elk conflicts, which would inform subsequent responses (principles 4 and 5 of adaptive management).

We recommend universal use of the WIR system by CDFW staff for human-elk conflicts (including CDFW staff cataloging incident reports received through means other than the WIR system). Changes to the WIR system that could help facilitate monitoring and adaptive management include the addition of fields to: describe the action and monitoring plan, enter monitoring data, evaluate efficacy of the response, and changes to the response as appropriate. Additionally, more thorough quantification of economic losses due to human-elk conflicts could be informative in developing loss-tolerance levels as part of an adaptive management model. Universal use of the WIR by CDFW staff may facilitate more comprehensive monitoring and rapid responses to conflicts that contribute to effective management needed to facilitate coexistence of humans and elk (Mekonen 2020).

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FULL RESEARCH ARTICLE

Relocation of habituated black bears in the Klamath Mountains of California: an adaptive management case study

ROBERT J. SCHAEFER*[1], DENNIS MOYLES[2], STEVEN MCDONALD[1], MONTY CERVELLI[1], AND DANIEL BECK[1]

[1] *California Department of Fish and Wildlife, 1625 S. Main, Yreka, CA 96097, USA*

[2] *Siskiyou County Department of Agriculture, Predatory Animal Control Specialist, 525 S. Foothill Drive, Yreka, CA 96097, USA*

**Corresponding Author: cervusphile@gmail.com*

Black bear (*Ursus americanus*) populations in California have increased in abundance and distribution despite rising trends in the urban encroachment of wildlands. As human-black bear conflicts increase, opportunities to study the relocation of black bears in an adaptive management setting are important for improving the management of this high-profile species. Habituated black bears, some tamed and made tractable through human-controlled food conditioning, were relocated to a remote region of the Klamath Mountains to analyze home range use, survival, return rates, and mortality. Relocated black bears with known outcomes demonstrated an 80% return rate, with 55% not surviving beyond five months. Female bears established home ranges significantly larger than males, and may suggest an enhanced maternal instinct in search of similar nutritional conditions prior to relocation. This study showed that the relocation of food-conditioned black bears resulted in high return rates, poor survival, and risk to public safety.

Key words: habituated, home range, Klamath Mountains, public safety, relocation, return rate, survival, telemetry, tractable, *Ursus americanus*

Black bear (*Ursus americanus)* populations in California have increased in abundance and distribution despite rising trends in the urban encroachment of wildlands (CDFW 2016; RJS, personal observation). With California's human population projected to reach 51 million by 2060 (PPIC 2018), the potential for increase in human-black bear conflicts is anticipated (Spencer et al. 2007). As a public trust wildlife agency, the California Department of Fish and Wildlife (CDFW) is responsible for the management of black bears. Human dimensions factors, such as strong public emotions and sociopolitical influences, can play a major role in the conflict mitigation of these charismatic carnivores (Manfredo and Dayer 2004).

Human–black bear conflict is commonly associated with the concentration of anthropogenic food resources available to wildlife. Habituation is the term often applied to black bears in close proximity to humans and is defined as a decreased responsiveness to a stimulus with repeated presentation (Blumstein 2016). Habituation has been distinguished from tolerance, which is the intensity of disturbance that an individual tolerates without responding in a defined way, but both terms are commonly interchanged (Nisbet 2000). Human-controlled food conditioning differs from habituation or tolerance in that it shapes a black bears behavior through positive reinforcement (food reward) and can lead to an attraction to humans. In these cases, black bears can become tamed and tractable, protective of humans, and lose denning instincts (Caton 1886; Beckman and Berger 2003; Vickery and Mason 2003). Labeling a bear as habituated because it displays tolerance towards people can be a misuse of the term, premature, or inaccurate, and may curtail further inquiry into the causes behind this behavior (Smith et al. 2005). To facilitate a science-based management approach for habituated black bears, managers should clearly distinguish between the differences and causal mechanisms in the habituated behaviors when setting management objectives (Gunther et al. 2004).

Preventing black bears from becoming conditioned to human food sources is the foundation of most bear management programs (Spencer et al. 2007). Evaluating the outcome of policies governing how human-black bear conflicts are managed is important (Beckmann and Lackey 2004). Relocation is a non-lethal black bear management tool where the post-relocation homing instincts of these highly mobile large carnivores is well documented (Beckmann and Lackey 2004; Landriault et al. 2009). It has been suggested that the post-relocation homing success displayed by adult animals is a consequence of increased navigational ability gained by experience and fidelity to established home ranges (Rogers 1986; Landriault et al. 2006). However, in extreme cases of habituation when food conditioning has eroded the natural behaviors of black bears, the effects on homing instincts are less understood (Vickery and Mason 2003; Herrero et al. 2005).

Adaptive wildlife management seeks to improve the integration of science and management by focusing decision-making on hypothesis-testing and structuring management actions as field experiments (Enck et al. 2006). This can allow shared learning among scientists, managers, and stakeholders and can provide integrated approaches when resolving difficult wildlife management issues (Lee 1999; Spencer et al. 2007). In California, where policies generally prevent the relocation of habituated black bears, research opportunities describing the behavioral details and outcomes when relocation is used are rare. Although most the public prefers non-lethality when resolving human-black bear conflict, killing the offending animal is still required for protecting public safety and property from depredating wildlife.

We discovered a unique and illegal wildlife feeding violation at a remote private residence in the Klamath Mountains of northwestern California. Wild black bears had been under the influence of human-controlled food conditioning for >20 years where many of the black bears had become tamed and tractable, were cohabitating with humans, and presenting significant conflict and safety issues with nearby landowners and the public. The relocation of these black bears presented an opportunity to collect and analyze quantitative data for managing human-black bear conflict where human-controlled food conditioning has been used.

METHODS

Study Area

The Klamath Mountains are some of the most rugged and topographically diverse ranges in California (Fig. 1). With steep mountain peaks exceeding 2500 m separated by low lying river valleys, it remains one of the most pristine and least populated regions in California. The World Conservation Union (CDFG 2007) recognizes these ranges for their biological diversity and as an area of botanical significance. The study area includes federal Wilderness Areas, culturally important tribal lands, and a climate that varies considerably with more rainfall than any other part of the state where heavy snowfall is contrasted by summer temperatures often exceeding 37° C.

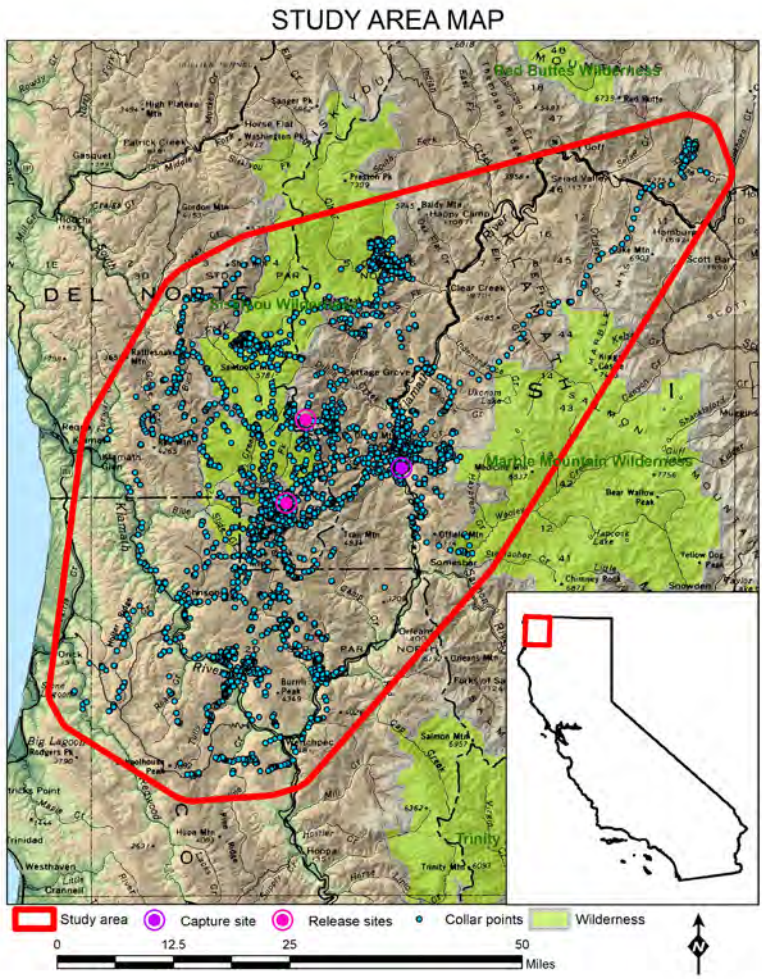

Figure 1. Study area in northwestern California showing capture and release sites and satellite locations for 8 relocated black bears.

These moist inland forests are dominated by conifer species including Douglas fir (*Pseudotsuga menziesii*), ponderosa pine (*Pinus ponderosa*), and sugar pine (*Pinus lambertiana*), with high elevation sub-alpine forests consisting primarily of white fir (*Abies concolor*), red fir (*Abies magnifica*), western white pine (*Pinus monticola*) and mountain hemlock (*Tsuga mertensiana*). Black oak (*Quercus velutina*) and white oak (*Quercus alba*) forests can be found at lower elevations with related species including tan oak (*Lithocarpus densiflorus*) and chinkapin oak (*Quercus muehlenbergii*) also present. Where shrubs are interspersed, they may include huckleberry (*Vaccinium ovatum*), manzanita (*Arctostaphylos klamathensis*), *Ceanothus* sp. and *Prunus* sp.

The rich fauna of the region contains a complement of terrestrial predators commonly represented by the black bear (*Ursus americanus*), mountain lion (*Puma concolor*), coyote (*Canis latrans*) bobcat (*Lynx rufus*), and gray fox (*Urocyon cinereoargenteus*). Native ungulates including the Roosevelt elk (*Cervus canadensis roosevelti*) and black-tailed deer (*Odocoileus hemionus*) occur throughout the area, with special status mammal and bird species highlighted by the fisher (*Pekania pennanti*), American marten (*Martes americana*), northern spotted owl (*Strix occidentalis caurina*) and northern goshawk (*Accipiter gentilis*). The low-lying river valleys drain the Klamath River watershed where sharp declines in fish populations have led to special status listings for several of these species.

Capture, Marking, and Monitoring

We captured black bears with baited culvert traps within 50 m of where the illegal feeding was occurring using methods prescribed by the CDFW Wildlife Investigations Lab (CDFW 2012). Captured bears were immobilized with combinations of telazol® and medetomidine, with one individual receiving butorphanol tartrate, azaperone tartrate and medetomidine hydrochloride (BAM®). We physically examined bears, monitored vital rates, determined sex and weight, estimated ages (Heffelfinger 1997), and applied ear tags showing an identification number and non-consumption warning label. A body condition score was estimated for each bear using a one (lowest) to four (highest) scale based on the average of bone prominence scores measured at 5 locations (Noyce et al., 2002). We attached a satellite telemetry collar (Vectronics®) with ~9 months of battery life to randomly selected bears that provided hourly GPS locations and mortality notifications. Bears were transported under anesthesia to a highly remote and inaccessible release point ~30 km from the capture site where they were removed from traps, anesthesia reversed, and monitored until ambulatory. Recaptured and injured black bears were humanely euthanized according to capture protocols and methods described by the WIL (CDFW 2012).

We monitored the mortality status, return rate, and home range use of collared black bears with ground telemetry and with satellite locations until the collars stopped transmitting. When a mortality occurred, we investigated within 48 hours when feasible and evaluated for a cause-specific death (Schaefer et al. 2000, Bender et al. 2004). A relocated black bear was considered "returned" when it was recaptured, observed, or photographed near the capture site, detected with ground telemetry, or satellite locations showed movements within 4 km of the capture site. Survival was determined as the number of days a black bear was known to survive after relocation. Outcomes could be determined for collared black bears by monitoring their status during the lifetime of the collar, or for non-collared black bears by ear tag number when recaptured, observations post relocation, or by remote cameras monitored near the capture site.

Home Range and Statistical Analysis

We used ArcMap (ESRI, Redlands, CA) to create a minimum convex polygon around all satellite locations for individual black bears which uses a convex hull to estimate home range size. Due to the long distances moved quickly by many collared black bears and the short duration some bears were alive, this allowed us to examine the extent of a black bears movements. For statistical comparisons between sexes, we used a 2-sample t-test (95% CI) to determine differences in home range size for collared black bears, and for survival days of relocated black bears with known outcomes.

RESULTS

We captured seventeen black bears (10 males and 7 females) during 11 trap nights between 7 August 2017 and 20 October 2017 ranging in weight from 20–204k (mean = 126 k) (Table 1). Among captured black bears, 13 were relocated, three were euthanized due to injuries from other bears, and one released at the capture site due to weather issues. All relocated black bears were ear tagged and eight animals (4 males and 4 females) were equipped with satellite telemetry collars.

For relocated black bears where outcomes could be determined, 80% (8 of 10) returned to the capture site within 23 days (mean = 8.5; range 3–23), and 55% (5 of 9) died within 140 days post relocation (mean = 79.6; range 51–140). Two collared black bear mortalities could be investigated promptly showing only evidence of weight loss as a possible cause of death. There was no difference in survival between sexes ($P > 0.05$), but female home-ranges (mean = 1106.15 km²) were significantly larger than males (mean = 197.63 km²; $t = -9.501$, $df = 3$, $P = 0.0003$).

DISCUSSION

Relocation is an ineffective management tool for reducing food-conditioned black bear conflict, as evidenced by the high mortality and return rate of relocated bears (Rogers 1986; Hopkins and Kalinowski 2013). Many black bears traversed some of the most challenging terrain in California to return within a few days to the capture site. Moreover, return rates were likely underestimated as the outcomes for 3 non-collared black bears could not be determined and reports of two ear tagged black bears killed by nearby landowners for safety reasons could not be confirmed. Some studies have suggested that as relocation distances increase, return rates may decline (Laundrialt et al. 2009; Rogers 1986). In this study black bears were captured in a sparsely populated and highly remote area adjacent to a federal wilderness area and moved to some of the most inaccessible terrains in northern California. Due to the remoteness of this area, attempting to increase the relocation distance would have resulted in extensive and potentially unsafe transport times and closer proximity to human population centers.

The survival of relocated black bears was remarkably low as most with known outcomes did not survive beyond 140 days. For two collared black bear deaths that could be investigated promptly, a dramatic decline in observed body weight was the only factor found to be associated with death. These black bears died at 51- and 67-days post-relocation and were found with no obvious signs of physical trauma, injury or disease but with significant declines observed in body condition. Both animals were in excellent nutritional condition at the time of capture and relocated to habitats ideal for black bears. The human-controlled food

Table 1. Biological characteristics, survival, return rate, home range estimates, and outcomes for 17 collared and non-collared black bears captured and relocated during 11 trap nights near Somes Bar, California from 12 August 2017 through 19 October 2017.

ID#	Age	Weight (kg)	Sex	Days Until Return	Days Alive	Home Range km²	BCS*	Outcome
Collared Bears								
111	5–7	136	M	3	68	94.68	4	Recapture/euthanize
114	6–9	158	M	5	67	291.81	4	Mortality/poor nutrition
103	3–5	77**	F	8	na	888.70	3	Stopped transmitting/267 days
110	6–9	204	F	23	na	1234.2	4	Stopped transmitting/274 days
112	6–9	181	F	nr	140	1258.95	4	Killed by public
108	12	163**	M	8	51	145.97	4	Mortality/poor nutrition
107	6–9	158	M	nr	na	258.09	4	Stopped transmitting/175 days
106	6–9	113	F	4	na	1042.72	3	Stopped transmitting/62 days
Non-collared Bears								
512	5–8	90	F	11	na	na	3	Killed by public
373	5–8	136	F	9	72	na	4	Recapture/euthanize
NA	6–9	204	M	na	na	na	4	Euthanized due to injury
105	3–5	90	M	na	na	na	3	Unknown
NA	1	20**	M	na	na	na	1	Euthanized due to injury
102	6–9	181	M	na	na	na	4	Unknown
113	3–5	136	M	na	na	na	4	Released at capture site
109	2	57	M	na	na	na	2	Unknown
NA	3–5	45	F	na	na	na	2	Euthanized due to injury

* BCS = Body Condition Score
** = Actual Weight
nr = No Return
na = Not available

conditioning experienced by these black bears may have led to a loss of natural behaviors and inability to adapt to fluctuating conditions that reduced their survival in the wild (Stiver et al. 1997; Vickery and Mason 2003).

Home range results were difficult to interpret due to small sample size and the inability to quantify a level of habituation for individual black bears. Alt et al. (1980) and others found that among wild bears, males maintain home ranges about 4 times larger than females. Beckmann and Berger (2003) showed that urban black bears had significantly smaller home ranges in comparison to non-urban individuals. Pop et al. (2012) suggested that home range sizes were strongly affected by the previous experience of the individual bear with humans, and found that habituated bears that are relocated will first explore the unknown release site prior to dispersing to their former home range. It has also been hypothesized that adult females benefit from a strong desire to return to their established home range where they have been able to meet the nutritional requirements necessary for reproduction (Rogers 1976;

Elowe and Dodge 1989). The extensive home ranges quickly established by females in this study were likely influenced by human-controlled food conditioning, relocation to unfamiliar environments, and a search for similar food conditioned circumstances prior to release.

The injuries for three black bears discovered upon capture were severe and consistent with bite wounds between conspecifics. When initially approaching the residence where the long-term feeding had occurred, 11 black bears could be observed at the residence behaving in a tamed and tractable manner (Fig. 2). During this period there were significant increases in public safety issues also being reported by adjacent landowners and motorists on the nearby highway for black bears attracted to humans (Fig. 3). Bears are considered the least social group among the carnivores (Gittleman 1989).Intraspecific killing has been well documented (Garshelis 1994), where several general factors driving aggression between conspecifics include population regulation, dominance disputes, and reproductive advantage (Amstrup et al. 2006). In this situation, the concentration of black bears resulting from decades of human-controlled food conditioning likely resulted in unknown rates of intraspecific aggression and mortality. It is also worth noting that the primary individual responsible for the food conditioning of these black bears had visible bear induced injuries and scars to their arms (personal observations RJS, DM, SM, MC).

A female black bear that displayed docility in the trap had lost a front leg near the shoulder joint and walked on three legs, but the injury was healed, and she was collared and relocated. This bear did not return to the capture site but established a home range of 1234.25 km² in 140 days post relocation before being killed by the public for entering a structure. This remarkable journey across major rivers and terrain with only 3 legs is a testament to a black bears ability to survive, but also suggest a search for similar habitat conditions and food availability (Fig. 4).

CDFW black bear policy states that habituated black bears are not candidates for relocation and will be either humanely euthanized or placed in a permitted animal care facility (CDFW 2019). The decision to relocate these black bears provided the rare opportunity to study relocation behavior in food conditioned black bears, but it also exposed the risk of this technique as an acceptable management option.

Figure 2. Residence in northwestern California where human-controlled food conditioning of black bears occurred for >20 years. Photo Credit: R. Schaefer

Figure 3. Photo taken by unsuspecting motorist when stopped on highway 96 in Siskiyou County for a lunch break near the residence where the human-controlled food conditioning occurred. Photo Credit: S. Schaefer

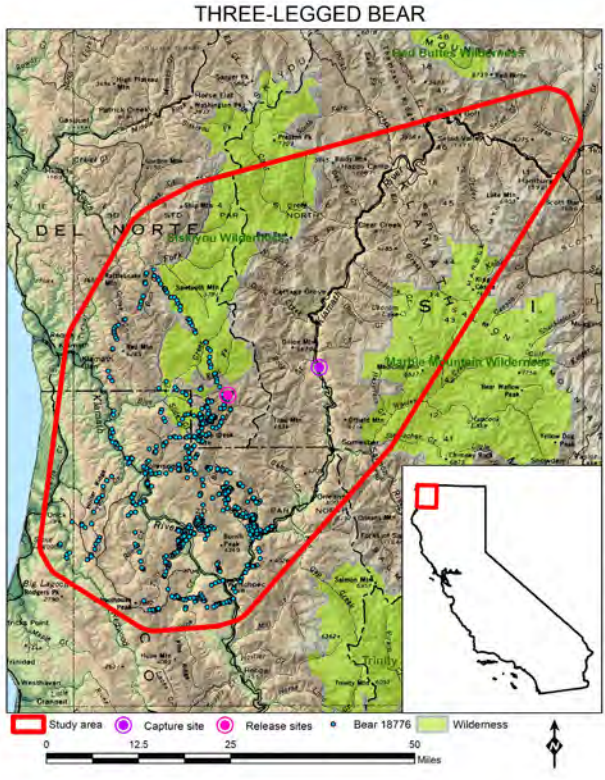

Figure 4. Satellite locations showing the extensive movements of a food conditioned 3-legged black bear that was killed by the public after 140 days post-relocation in the Klamath Mountains of northwestern California.

We propose that compassion without reason can result in cruelty without guilt, and encourage managers to consider this case study when facing similar decisions in the future. Bath (1998) postulated that the public should not dictate wildlife policy, or wildlife management actions. Whether for endangered species protection, public safety, or human-wildlife conflict, the human dimensions of wildlife management requires agencies to bridge the public's trust when lethal actions are advised (Schaefer et al. 2000; Talbert et al. 2020). This requires leadership capable of articulating the consequences or potential risks facing humans and wildlife in modern society when difficult decisions may be required. In this instance, relocation failed to resolve this difficult human-black bear conflict humanely and with public safety as a primary concern.

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FULL RESEARCH ARTICLE

An innovative temporary escape ramp for deer and other wildlife

GINA E. MORIMOTO[1*], ANAE` B. OTTO[2], AND LAURA L. BURKHOLDER[1]

[1] *Pacific Gas and Electric Company, 3401 Crow Canyon Road, Room 150F, San Ramon, CA 94583, USA*

[2] *United States Forest Service, Sierra National Forest, Bass Lake Ranger District, 57003 Road 225, North Fork, CA 93643, USA*

**Corresponding Author: gina.morimoto@pge.com*

Concrete-lined water conveyance canals can be a significant source of mortality for ungulates and other wildlife, which can drown or become entrapped. Various types of wildlife escape structures have been deployed in canals with limited success. From 2011 to 2018, we used camera traps to monitor mule deer (*Odocoileus hemionus*) use of three different temporary wildlife escape structure designs with the goal of developing an effective escape structure for fawns. We monitored three to five locations at a hydroelectric water conveyance canal, operated by Pacific Gas and Electric Company in the foothills of Central California on the Sierra National Forest, in which trapped fawns had been detected previously during the maintenance period when the canal was dry. Mule deer activity and ramp use varied by year. During the monitoring period, deer were detected in the canal in all years except 2016 and 2017. Fawns and adults used the temporary escape structures to exit the canal in four of these years and 50% of mule deer detections showed ramp use overall. No deer were detected using the escape structures until jute netting and debris were added to the surface of the escape ramps in the third monitoring year. Prior to this modification, fawns were detected trapped in the canal investigating the ramps, but not using them to exit the canal. Deer may be more likely to utilize ramps covered with materials that mimic native ground cover. Seven other wildlife species were detected entering and exiting using the ramps with a general increase in use over years. Our temporary escape ramp design for small canals, when dry, appears to be novel and may be applicable in other areas. When compared to fencing or covering the canal, it is a relatively low-cost solution to reduce animal entrapment.

Key words: canal, drowning, entrapment, escape ramp, fawn, mule deer, *Odocoileus hemionus*, wildlife escape ramp

In California, there are over 12,000 km of canals that transport water throughout the state for industrial, residential, and agricultural purposes. These types of open water conveyances can pose a threat to wildlife by fragmenting habitat, disrupting daily or seasonal movements, and can result in animal mortalities from drowning or entrapment (Rautenstrauch and Krausman 1989; Peris and Morales 2004). In some areas, concrete lined canals have been shown to be a significant source of wildlife mortality, particularly for ungulates (Latham and Verzuh 1971; Krausman et al. 1992). Mule deer (*Odocoileus hemionus*) are more likely to drown in concrete lined than in earthen canals (Bucci and Krausman 2015). One five-year study recorded 538 dead mammals in a 24.1-km concrete lined canal in northern Spain, 22% of which were roe deer (*Capreolus capreolus*; Peris and Morales 2004).

In the foothills of central California, Pacific Gas and Electric Company (PG&E) operates a hydroelectric facility with a network of canals that traverse portions of the Sierra National Forest. Mule deer fawns have become entrapped in the vertical-walled section of canals during the summer maintenance period when these water conveyance features are dry and not operating. In the Sierra Nevada, this time period coincides with the local neo-natal mule deer fawning period (Kroeker 2018).

Various types of wildlife escape structures have been deployed in canals with limited success (Nelson et al. 1978; Krausman et al. 1992). A combination of steps, ramps, and directional cables successfully allowed trapped mule deer to escape from a large concrete-lined canal with sloped sides in southwest Arizona (Rautenstrauch 1987). Few relevant solutions were found in the literature for the type and size of seasonally dry canal structures present in the study area. Stacked hay bales were successfully used as temporary escape ramps by deer and elk in a Washington state canal (Latham and Verzuh 1971; Nelson et al. 1978).

We tested stacked hay bales and escape ramps of our own design at five locations within a 2-km stretch of canal in which trapped fawns had been detected previously. We used camera traps to monitor attempted use and animal behavior around the escape structures, allowing us to adaptively modify structure design based on our observations during the study period. Our objectives were 1) to determine the effectiveness of our escape structures for mule deer and 2) to monitor which species of wildlife used the escape structures to exit the canal. Our study was focused on specific management objectives and is best described as applied research conducted to inform adaptive management of an observed issue.

METHODS

Study Area

We conducted our study along a canal that is owned and operated by PG&E in North Fork, California (37.229, -119.510). The study area is in the central Sierra Nevada foothills with elevations ranging from 853.4 to 867.2 m (Fig. 1). The climate in the study area is characterized as Mediterranean, with cool wet winters and hot dry summers. Average monthly temperatures range from 0°C in January to 35°C in July and yearly precipitation averages 85 cm. Snowfall is rare, averaging 5 cm annually. Dominant vegetation in the upper section of the canal consists of montane hardwood-conifer, primarily comprised of black oak (*Quercus kelloggii*), incense-cedar (*Calocedrus decurrens*), and ponderosa pine (*Pinus ponderosa*). The lower section of canal runs through blue oak woodland dominated by blue oak (*Quercus douglasii*), interior live oak (*Quercus wislizenii*), and California buck-

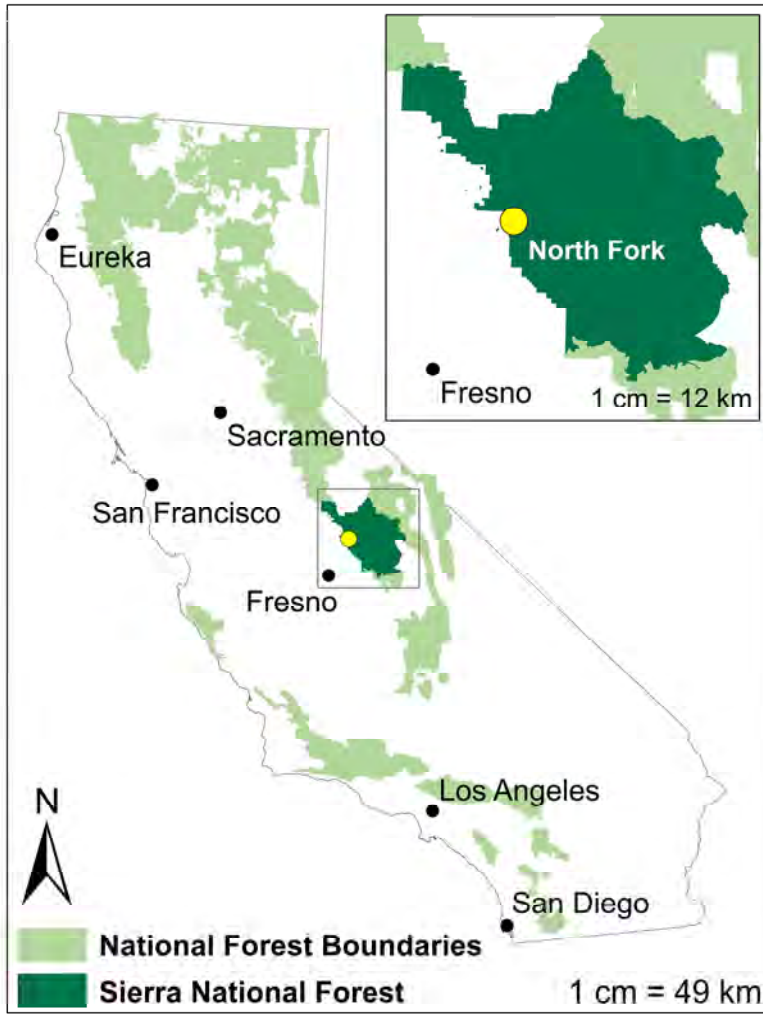

Figure 1. Study area located in North Fork, CA, USA.

eye (*Aesculus californica*), interspersed with annual grassland. Both resident and migratory mule deer use the study area.

The canal is part of the Crane Valley Hydroelectric Project (Federal Energy Regulatory Commission [FERC] Project Number 1354). The canal is 2.88 km long, with approximately 2 km of exposed canal that is mostly lined with concrete. We determined that the highest area of concern was the box flume portion of the canal due to the tendency for deer to try to jump over and subsequently fall in. The typical box flume canal dimensions are 1.83 m wide by 1.5 m tall, with vertical sides. There are nine crossings (bridges) suitable for deer along the 2 km portion of exposed canal. We began our study with five sites and gradually reduced the sites to three. These sites were selected based on areas where high deer activity was recorded in a Project-wide canal crossing study and where the public identified fawns falling into the canal.

Temporary Escape Ramp Design

We required an escape ramp that met the following criteria: 1) easy to deploy and remove during/after the annual summer maintenance period; 2) would not affect the structural integrity of the canal; and, 3) economical (inexpensive to construct, deploy, and maintain). Initially in 2011, hay bales were stacked in a step configuration within the canal (Fig. 2). Four to six wheat hay bales were stacked at each site.

Figure 2. Different iterations of temporary escape structures used from 2011–2018 in canal located in North Fork, California: (a) Hay bales arranged in step configuration (2011), (b) Aluminum platforms covered with rubber sheets (2012), (c) Aluminum platforms covered with rubber sheets and sandbags installed at base of ramp (2012), (d) Aluminum platforms covered with rubber sheets, sandbags deployed at base of ramp, and jute netting and debris utilized (2013), (e) Aluminum platforms covered with rubber sheets, sandbags deployed at base of ramp, jute netting and debris utilized, and camera trap attached to canal crossbeam (2017).

Due to the lack of successful results the previous year, in 2012 we used a different temporary escape structure designed specifically for the canal. The design consisted of aluminum stage platforms covered in neoprene rubber sheets that were 0.64 cm thick by 50.8 cm wide and secured to the canal with galvanized steel hardware to increase traction (Fig. 2; Appendix I). At each of the five sites, we used two 3.66 m by 0.56 m aluminum stage platforms that were placed side by side to serve as the ramp. At three sites that did not have existing bridges, we placed two 2.44 m by 0.56 m aluminum stage platforms side by side to create a bridge. The platforms were secured together with 0.95 cm steel bolts with washers. The ramps were secured to the bridges with 1.27 cm-diameter U-bolts. The assembly was secured to the canal walls using steel bolts and locked to deter theft. At two sites, wood/iron supports were removed on top of the canal sides to install the ramps. The ramp angles ranged from 27° to 32°. These angles were hypothesized to avoid attracting deer into the canal, while providing a means to exit the canal. From 2013–2018 we added jute netting and debris (i.e., dirt, plant material) on top of the rubber sheets to create a more natural appearance, and sandbags with native fill at the bottom of each ramp to eliminate any gaps that might be visible to wildlife (Fig. 2). Wooden slats were placed horizontally along sections of ramps in 2013 but were not attached in subsequent years. The entire ramp assembly was constructed with materials purchased from a local hardware store for under $1,000 per site; this met our economical criterion.

Camera Trap Models

We used various camera traps during our study to monitor use of the temporary escape ramps as camera technology improved (Table 1). One camera trap was deployed per ramp site. The cameras were placed in metal security boxes with metal locks. Camera trap placement varied per site depending on the availability of stationary objects for camera installation. Each camera was secured to a stationary object such as a canal crossbeam inside the canal or t-post adjacent to the canal with Master Lock Python™ cable locks and bungee cords. The camera traps were generally placed with the entire ramp in the field of view to detect animals entering and exiting the canal. Trigger distances and camera angle/height placement were thoroughly tested during camera setup at each site to ensure the cameras would trigger if an animal used the temporary ramps.

Table 1. Camera trap models used during our study from 2011–2018 at canal in North Fork, California.

Camera Model[a]	Year(s) Used	Number of Photos per Trigger	Photo Delay Interval (seconds)
TrailMaster (35 mm film)	2011	1	12
PhotoHunter™ (35 mm film)	2012	1	60
Moultrie® Model M-880	2013–2015	4	5
Reconyx Hyperfire™ Model HC600	2016–2018	5	0

[a] Different camera models were used as technology improved.

Escape Ramp Deployment and Camera Trap Monitoring

Escape ramp deployment was timed with annual canal maintenance. The annual maintenance period generally was a period of six weeks beginning in July and ending in August. The canal was mostly dry during this period. We initially deployed escape ramps at five sites from 2011 through 2012. We gradually scaled down the sites to three from 2014 through 2018 after determining lack of mule deer use at two sites (Table 2). A two to four-person crew installed the escape ramps after clearance was obtained to enter the dry canal. We installed the camera traps to coincide with the ramp deployment. We generally conducted weekly checks of the cameras and ramps throughout the monitoring period. During each camera check, we downloaded photos, checked the batteries, noted any sightings or relevant information at the site (e.g., vandalism), and adjusted the camera if necessary. At the end of the maintenance period, a two to four-person crew removed the ramps. We generally removed the cameras a week or two after the ramps were removed. We defined the monitoring period to coincide with installment and removal of the escape ramps (Table 2).

At the end of the monitoring period, we manually sorted through the photos and summarized the data by site, date, time, temperature, photo file name, species, behavior, and whether the target species, mule deer, used the escape ramps, as well as other wildlife that used the ramps. We also recorded other variables that may have affected deer activity in our study area, such as drought, wildfires, human activity, and water year type.

Data Analysis

We summarized camera monitoring data by tallying deer and other wildlife detections by site and year. We considered detections of the same species at the same site that were 30 minutes or more apart to be a single detection. Detections may include the same animals on multiple occasions. We chose 30 minutes between detections based on review

Table 2. Summary of escape ramp structure type, number of sites, and monitoring period when ramps were installed and removed throughout our study from 2011–2018 in North Fork, CA, USA.

Year	Escape Ramp Structure Type[a]	Number of Sites	Monitoring Period (Ramps Installed/Removed)
2011	Ramp Type 1	5	13 Jul 2011–8 Aug 2011
2012	Ramp Type 2	5	25 Jul 2012–22 Aug 2012
2013	Ramp Type 3, jute netting/debris installed on 19 Jul 2013	4	10 Jul 2013–15 Aug 2013
2014	Ramp Type 3	3	3 Jul 2014–7 Aug 2014
2015	Ramp Type 3	3	1 Jul 2015–6 Aug 2015
2016	Ramp Type 3	3	7 Jul 2016–11 Aug 2016
2017	Ramp Type 3	3	12 Jul 2017–16 Aug 2017
2018	Ramp Type 3	3	27 Jun 2018–20 Sep 2018

[a] Ramp Type 1 = Hay bales; Ramp Type 2 = Aluminum platforms covered with rubber sheets; Ramp Type 3 = Aluminum platforms covered with rubber sheets, sandbags deployed at base of ramps, jute netting and debris utilized

of the camera data to avoid double counting individuals that had not yet moved from the site during a detection and to achieve an index of activity in and around the canal over the monitoring periods. If more than one animal was visible in a single detection, each individual animal was counted. For deer detections we simplified age into two classes, first year fawns were classified as fawns and all other deer were considered adults. We noted photographs resulting from false triggers (e.g., wind or other non-wildlife trigger) or with inconclusive blurry images, but we did not include these photographs in results. Detections are shown as number of detections not standardized by the number of camera monitoring days. Due to the small number of detections, dividing by camera monitoring days resulted in small values with negligible to no differences in overall trend among years, compared to raw detection numbers. Our results are descriptive due to our overall small sample size. We pooled detections for all sites. We did not make comparisons between sites because the objective of the monitoring was to determine an effective temporary escape ramp for trapped fawns in the 2-km canal section, not to compare use among sites.

We detected mule deer in the camera field of view both inside and outside the canal and used all deer detections combined as an index of deer activity to compare to deer entrapment to indicate whether the camera monitoring was effectively recording ramp use.

RESULTS

The number of camera monitoring days and sites varied by year due to factors such as timing of the annual maintenance period, stolen or vandalized cameras or escape structures, and site selection based on previous use observations. Camera monitoring days included the total number of days that a camera was deployed and in working condition at each site with a temporary ramp installed.

We detected several wildlife species in and around the canal, including mule deer, striped skunk (*Mephitis mephitis*), raccoon (*Procyon lotor*), opossum (*Didelphis virginiana*), Merriam's chipmunk (*Neotamias merriami*) , western gray squirrel (*Sciurus griseus*), California ground squirrel (*Otospermophilus beecheyi*), black-tailed jackrabbit (*Lepus californicus*), cottontail rabbit (*Sylvilagus audubonii*), dusky-footed woodrat (*Neotoma fuscipes*), black bear (*Ursus americanus*), mountain lion (*Puma concolor*), bobcat (*Lynx rufus*), gray fox (*Urocyon cinereoargenteus*), coyote (*Canis latrans*), California towhee (*Melozone crissalis*), black phoebe (*Sayornis nigricans*), and various other passerines, California quail (*Callipepla californica*), red-shouldered hawk (*Buteo lineatus*), Cooper's hawk (*Accipiter cooperii*), great horned owl (*Bubo virginianus*), and various bats.

We did not detect any animals using the stacked hay bales to exit the canal in 2011. Although fawns were detected in the canal in 2011 and 2012, they did not use the temporary escape structures to exit the canal (Fig. 3). We detected mule deer fawns and adults using temporary escape ramps to exit the canal in 2013, 2014, 2015, and 2018 (Figs. 3 and 4). We recorded the highest amount of ramp use in 2015 (62.5% of deer detected in the canal used ramps), followed by 2013 (57.1% of deer detected in the canal used ramps) and 2018 (50.0% of deer detected in the canal used ramps; Fig. 3). There were no detections of deer in the canal using the temporary escape structures to exit until after the installation of jute netting and debris onto the surface of the ramps in 2013 (Fig. 5). No deer were recorded using the ramps to enter the canal throughout the monitoring period.

We detected mule deer fawns in the canal (regardless of ramp use) during the monitoring period in all years except 2016 and 2017 (n = 20), while mule deer adults were observed

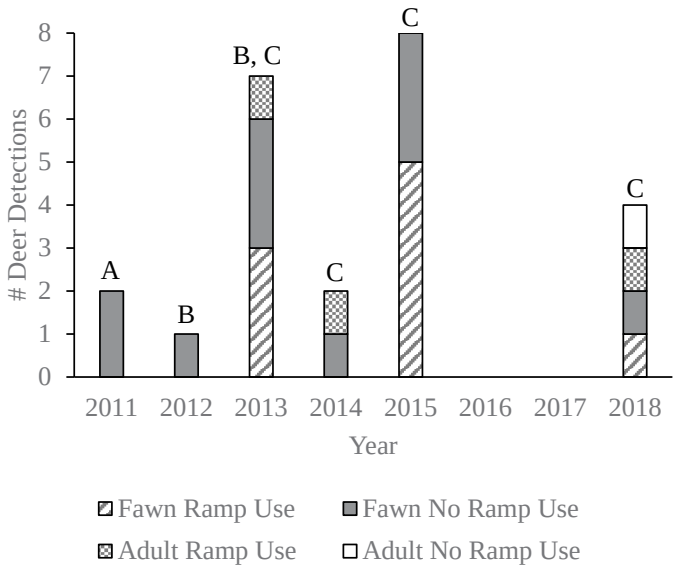

Figure 3. Number of deer detections inside canal located in North Fork, California for all sites from 2011–2018. Temporary escape structure designs: A = hay bales, B = aluminum, rubber covered ramps; C = aluminum, rubber, jute netting and debris covered ramps.

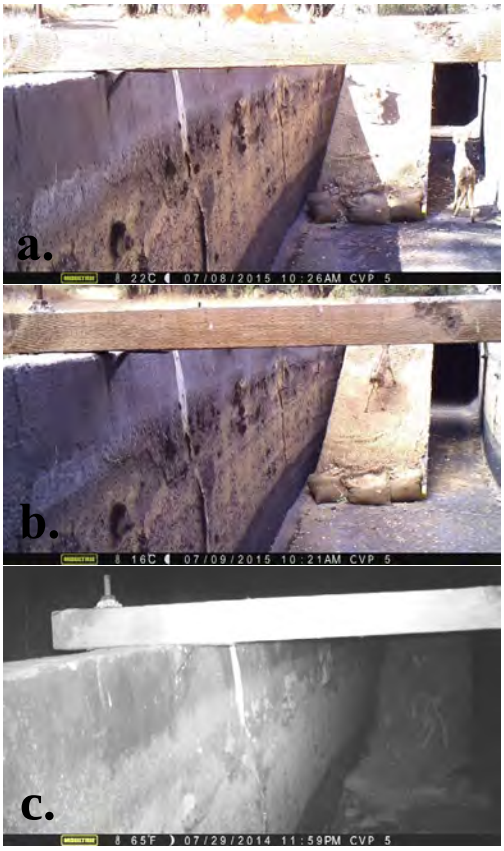

Figure 4. Examples of mule deer utilizing the temporary escape ramps to exit the canal from 2014–2015 in canal located in North Fork, California: (a) and (b) pair of trapped fawns use ramp to exit canal as mother doe observes from above (2015), (c) mule deer using ramp to exit canal at night (2014).

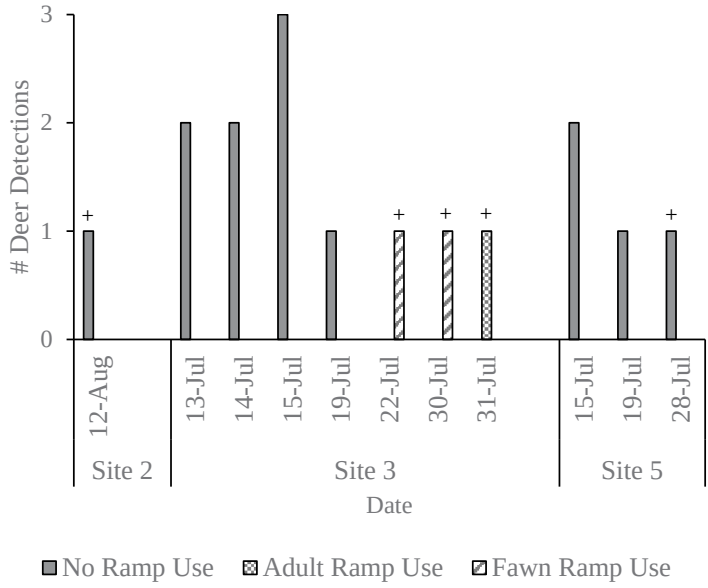

Figure 5. Number of deer detections inside canal located in North Fork, California by site compared with timing of jute netting and debris installation onto temporary escape ramps in 2013. Plus sign (+) indicates post installation of jute netting and debris.

in 2013, 2014, and 2018 (n = 4; Fig. 3). Overall deer activity varied by year. We detected the highest levels of mule deer activity in and around the canal in 2013 and 2018 (n = 47 and 21, respectively), followed by moderate activity in 2011 and 2015 (n = 12 and 13, respectively; Fig. 6). We recorded the greatest number of deer detections in critically dry and below normal water years, but this pattern was not consistent among years (Fig. 6). We detected other wildlife using the ramps to enter or exit the canal from 2012 to 2018 (Table 3 and Fig. 7), with a general increase in use over monitoring years.

DISCUSSION

We began our study in 2011 using hay bales placed in the canal after a search of the published literature (Latham and Verzuh 1971) indicated successful use in other larger canals. The hay bales did not appear to be a viable solution when tested in the study area due to the difficulty in deploying and maintaining the structures throughout the maintenance period. After we failed to detect any use of the hay bales by mule deer or other wildlife, we sought the help of a PG&E Engineer to design a temporary escape ramp. The new temporary ramp was deployed in 2012. While we did not record any photographic use of the new metal ramps, we observed small mammal tracks on one of the new ramps, indicating that it had used the ramp to exit the canal.

We had numerous problems with the film cameras used in 2012. For example, not capturing images of the small mammal that left tracks exiting the canal and a camera was stolen at one site. Therefore, we used digital cameras beginning in 2013 (Table 1), while keeping the same ramp design with some modifications (i.e., placing sandbags at the base of the ramps).

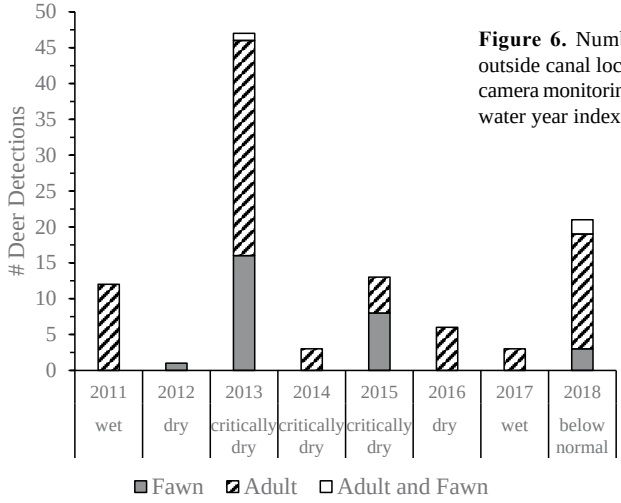

Figure 6. Number of deer detections inside and outside canal located in North Fork, California at all camera monitoring sites from 2011–2018 compared to water year index (https://cdec.water.ca.gov).

Table 3. Non-deer wildlife detected using temporary escape ramps in canal located in North Fork, CA, USA to enter and exit the canal from 2011–2018.

Year	Species	Total Detections	Camera Monitoring Days
2011	--	0	95
2012	Small mammal (tracks)	1	117
2013	Raccoon	5	152
	Western gray squirrel	2	
2014	Raccoon	3	108
	Bobcat	1	
	Coyote[a]	3	
2015	Striped skunk	2	111
2016	Raccoon	3	108
	Bobcat	2	
	Striped skunk	1	
2017	Opossum	1	108
	Raccoon	7	
2018	Opossum	7	258
	Raccoon	22	
	Bobcat[b]	5	
	Western gray squirrel	3	
	Red-shouldered hawk	1	
	Squirrel sp.	1	
	Gray fox	2	

[a] One detection of coyote carrying dead fawn out of canal using ramp to exit.
[b] One detection of two bobcat kittens using ramp to exit canal.

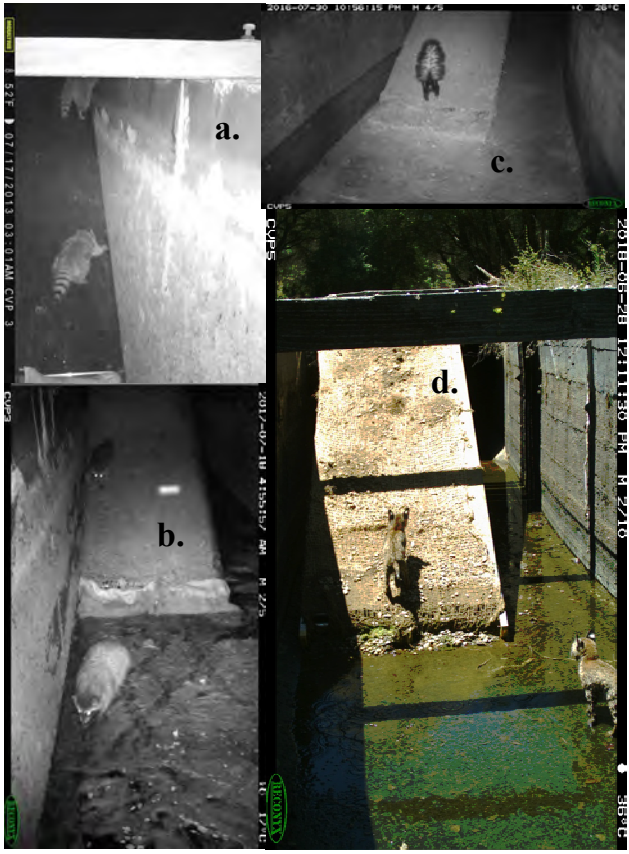

Figure 7. Examples of wildlife utilizing the temporary escape ramps to either enter or exit the canal from 2013–2018 in canal located in North Fork, California: (a) Raccoons using ramp to exit canal with no jute netting or debris installed (2013), (b) Raccoons using ramp to enter canal with jute netting and debris installed (2017), (c) Skunk using ramp to exit canal with jute netting and debris installed (2016), and (d) Bobcat kittens using ramp to exit canal with jute netting and debris installed (2018).

At the beginning of the 2013 camera monitoring period, we found a deceased fawn, two live fawns, and a cottontail rabbit that were trapped in the canal. One fawn and the cottontail rabbit were manually captured and released from the canal by U.S. Forest Service (USFS) staff, while the other fawn escaped the canal on its own. Upon reviewing the photos, we found that the fawns investigated the base of the ramps several times over three days but did not use the ramps. Rather than use the ramps, a fawn tried to jump out of the canal at the base of one ramp (Figs. 8a and 8b). After this discovery, we hypothesized that the fawns did not recognize the ramp as a means of escape due to the black surface of the ramps. We covered the surface of the ramps with jute netting and debris consisting of dirt and plant material on 19 July 2013. On 22 July 2013, we recorded our first successful use of the temporary escape ramps by mule deer fawns (Figs. 5 and 8c). Deer may be more amenable to using bridges and escape ramps covered with materials that mimic native ground cover (Peris and Morales 2004). That finding is similar to our observed change in ramp utilization after the jute netting and debris were added to the ramps. At the end of July 2015, the jute netting and debris were removed by an unknown person at the downstream-most site in our study area. Up until this point, trapped fawns successfully used the ramps with the jute netting and debris. Removal of the jute netting/debris covering coincided with the discovery of a trapped fawn that required manual capture and release by a PG&E crew.

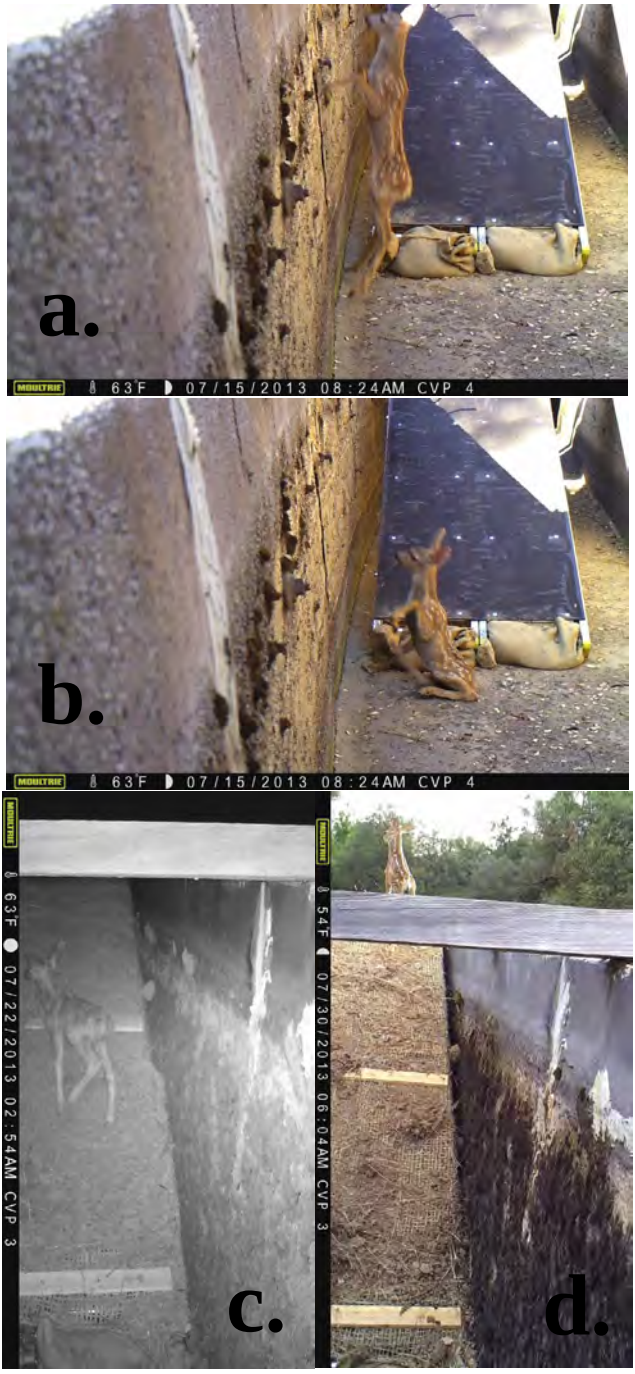

Figure 8. Example of adaptive modification of ramp design based on monitoring data at canal in North Fork, California: (a) and (b) Mule deer fawn attempts to jump vertically to exit canal while ignoring temporary escape ramp (15 July 2013). On 19 July 2013, jute netting and debris are added to the ramps. (c) and (d) mule deer fawns use ramp to exit canal on 22 July 2013 and 30 July 2013.

The temporary escape ramps with jute netting and debris were not 100% successful in encouraging fawns to exit the dry canal. In August 2013 after jute netting was installed, a fawn was manually captured and released by a PG&E crew. There was another instance of a trapped fawn manually captured and released by PG&E and USFS in July 2018. Forty-five percent of all fawns detected in the canal used the ramps to exit (Fig. 3). Of the remaining 55% of fawns detected in the canal, some fawns were manually captured and removed, fawns may have escaped through other areas of the canal, or cameras may have failed to detect fawns escaping via the ramps. Three new wooden bridges were installed in the vicinity of our study sites in 2016, which may have contributed to the lack of deer detected in the canal in 2016 and 2017 during the monitoring period. In 2017, three deceased fawns were found in the canal prior to the ramp installment and monitoring period. No deceased deer were found in the canal in 2016. Human activity and the presence of domestic dogs could have affected the ability of mule deer fawns to use the ramps as well.

We documented more mule deer in the canal during years of higher deer activity (2013, 2015, and 2018) compared to other years (Fig. 3). We did not observe mule deer in the canal during the monitoring period in 2016 and 2017 which also coincided with low deer activity around the canal (Fig. 6). By using the mule deer activity in and around the canal as an index, we felt that we were able to effectively detect deer activity in the canal.

Drought conditions existed from 2012–2016 and 2018, and fires occurred near North Fork from 2013–2015 and 2017 (Table 4). These environmental conditions could have contributed to annual variability in overall deer activity. Water was present in the canal at least during some portion of the camera monitoring period in all years except 2014 and 2016. Mule deer and other wildlife may have been attracted to the canal due to the presence of water, particularly in 2015 (fourth year of drought). Kroeker (2018) noted that the environmental stressors of drought, wildfire, and insect infestation are acting as a catalyst for habitat change across the San Joaquin River watershed. Kroeker (2018) observed changes caused by wildfire that benefit deer including seral stage reset and rejuvenation of mature browse plants. All of these changes could have affected deer movements or habitat use patterns; however, the extent of these potential effects is unknown and require further study.

While the focus of our study was on mule deer use, we found that other wildlife also used the ramps. Raccoons used the ramps most often, followed by bobcats and opossums (Table 3). The steep angle of the ramps appeared to deter deer from entering the canal, but it still allowed other animals to enter and exit using the ramps. Raccoons, bobcats, and

Table 4. Environmental conditions during temporary escape ramp study in North Fork, CA, USA.

Year	Drought Conditions? (Yes/No)	Fires Near Study Area (within 10 miles)
2011	No	None
2012	Yes	None
2013	Yes	Gold Fire, Aspen Fire
2014	Yes	Courtney Fire, Pines Fire, French Fire
2015	Yes	Corrine Fire, Willow Fire
2016	Yes	None
2017	No	Railroad Fire, Mission Fire
2018	Yes	None

opossums seemed to learn that they could enter and exit the canal over the years. In 2014, a coyote was observed carrying a dead fawn out of the canal.

While our temporary escape ramps allowed for at least 50% of mule deer to use the ramps, other modifications may improve the effectiveness. The angle of the ramps could be adjusted to a gentler slope. Caution should be taken so the angle is not so gentle that it provides a favorable point for fawns to enter the canal. Another potential modification is the use of wooden slats placed horizontally on the surface of the ramp to act as additional traction for mule deer fawns.

Over the course of our study, we were able to test the effectiveness of our new temporary escape ramps by adaptively making changes and conducting camera trap monitoring. We found that the escape ramps were used by wildlife species besides mule deer. Internet search engine results for "wildlife escape ramps" focus on small mammal/bird escape ramps from water troughs (Taylor and Tuttle 2007, USDA NRCS 2012) or deer jump outs related to highway fencing (Huijser et al. 2015). Designs are readily available for both types of structures. We developed a new temporary wildlife escape ramp designed to allow mule deer fawns to self-rescue from a dry vertical-walled canal. Our temporary escape ramp design for small canals appears to be novel and may be applicable in other areas. It is a relatively low-cost solution compared to fencing or covering the canal (Latham and Verzuh 1971).

ACKNOWLEDGMENTS

This study was a joint effort between PG&E and USFS Sierra National Forest. PG&E designed the ramps and paid for the materials and equipment. PG&E supplied the digital camera traps. Monitoring was split between the USFS and PG&E. We thank E. Doswald (PG&E) for designing the escape ramps and the PG&E Water Crew for installing and deploying ramps every year. T. Kroeker (California Department of Fish and Wildlife) was instrumental in providing advice and encouraged us to publish our work. S. Sutton-Mazzocco (USFS) took over monitoring in 2016, with assistance provided by T. Lowe (USFS). S. Johnson (PG&E) and A. Henke (PG&E) helped us monitor during the first year of this study. This study would not have been possible without the support of P. Merck (PG&E), C. Ferguson (PG&E), and J. Moore (PG&E). We thank multiple reviewers whose comments and suggestions helped improve and clarify this manuscript.

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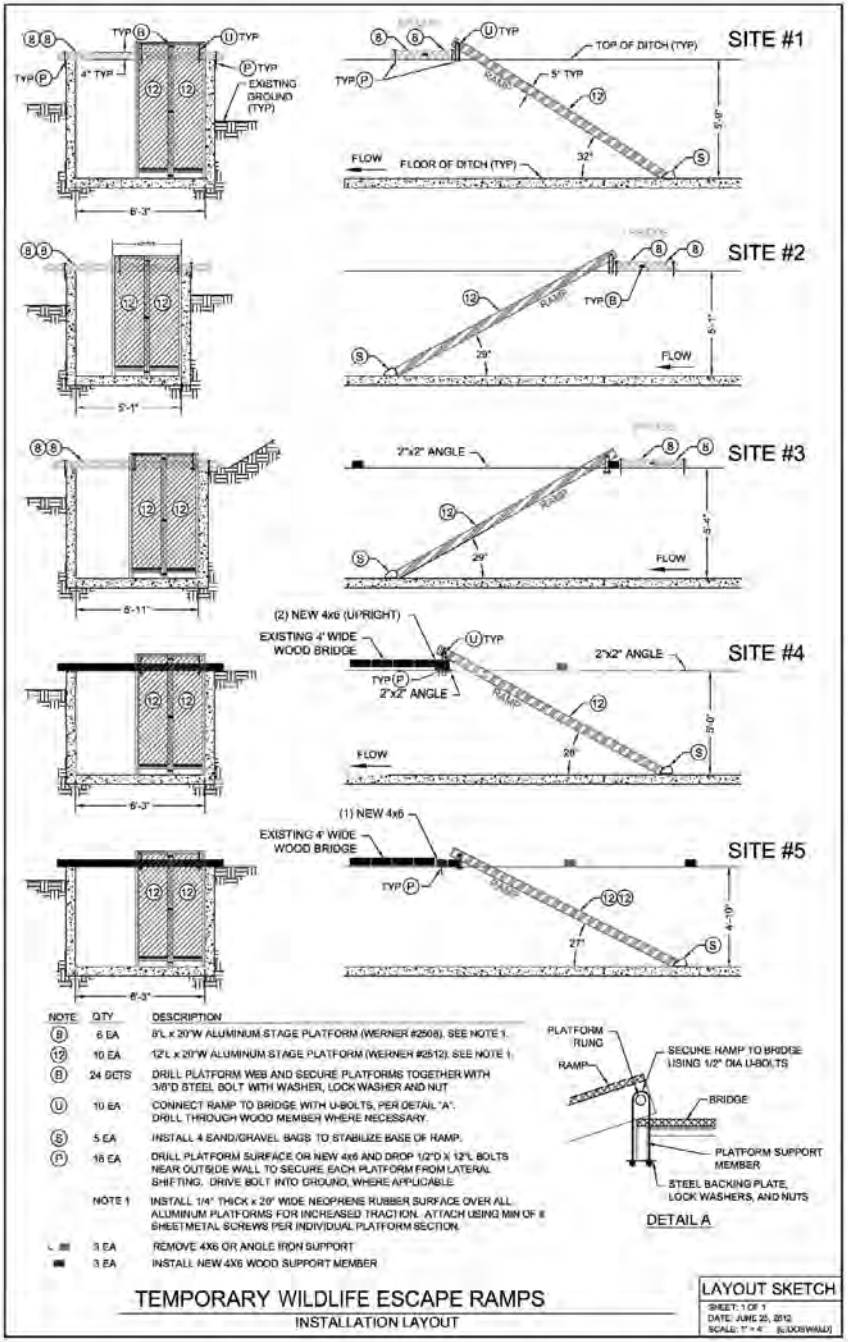
APPENDIX I

Temporary wildlife escape ramp engineering design for five original ramp locations in canal at North Fork, California.



Novel Coexistence & Conservation

Novel Coexistense & Conservation

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1. Western Snowy Plover (*Charadrius nivosus nivosus*) wintering at Crown Memorial State Beach, California. Photo Credit: Daniel Riensche, East Bay Regional Park District.
2. California sea lions (*Zalophus californianus*) are a popular attraction along coastal habitat in California. Photo Credit: California Department of Fish and Wildlife.
3. Western spotted skunk (*Spilogale gracilis*) in the Sierra Madre Mountains, California. Photo Credit: Johanna Turner, Cougar Conservancy.
4. Roosting pallid bats (*Antrozous pallidus*) observed while monitoring the colony. Photo Credit: California Department of Fish and Wildlife.
5. River otter (*Lontra canadensis*) catching and eating fish. Photo Credit: California Department of Fish and Wildlife.
6. Sierra Nevada mountain yellow-legged frogs (*Rana sierrae*) are restricted to higher elevation aquatic habitat. Photo Credit: California Department of Fish and Wildlife.

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REVIEW PAPER

Photovoltaic solar farms in California: can we have renewable electricity and our species, too?

BRIAN L. CYPHER[1]*, BRIAN B. BOROSKI[2], ROBERT K. BURTON[3], DANIEL E. MEADE[4], SCOTT E. PHILLIPS[1], PHILIP LEITNER[1], ERICA C. KELLY[1], TORY L. WESTALL[1], AND JASON DART[4]

[1]*California State University-Stanislaus, Endangered Species Recovery Program, One University Circle, Turlock, CA 95382, USA*

[2]*H. T. Harvey & Associates, 8080 N. Palm Avenue, Suite 205, Fresno, CA 93711, USA*

[3]*California State University-Monterey Bay, Applied Environmental Science, 100 Campus Center, Seaside, CA 93955, USA*

[4]*Althouse and Meade, Inc., Paso Robles, CA 93446, USA*

**Corresponding Author: bcypher@esrp.csustan.edu*

Photovoltaic solar power generating facilities are proliferating rapidly in California and elsewhere. While this trend is welcomed for many reasons (e.g., reducing greenhouse gas emissions), these facilities also can have profound environmental impacts, particularly to local species populations. These impacts become more significant when species of conservation concern are affected. In the San Joaquin Desert region in central California, a number of conservation measures have been routinely implemented on solar facilities, and these measures have facilitated continued use of the facilities by a number of species of conservation concern. Some of the more significant measures include permeable security fences, vegetation management, movement corridors, avoiding critical features such as dens and burrows, and vehicle speed limits. Detailed studies have been conducted on San Joaquin kit foxes (*Vulpes macrotis mutica*) using solar facilities in the San Joaquin Desert. Demographic and ecological attributes of foxes are similar between foxes using the facilities and foxes on nearby reference sites, and values for foxes on solar sites are within the ranges of values for foxes reported from sites within core population areas. Facilitated by the conservation measures, kit foxes are using at least six facilities in the San Joaquin Desert as are a variety of other species of conservation concern. This successful model also potentially could be adapted to other ecosystems and applied to facilities in regions outside of the San Joaquin Desert, such as the Mojave Desert. Determining whether species in other regions can use photovoltaic solar facilities and identi-

fying the most efficacious conservation measures will require time and testing, and these efforts would benefit from collaborative efforts among landowners, solar developers, natural resources agencies, researchers, and others. The San Joaquin Desert facilities and a recent demonstration facility in the Mojave Desert provide strong evidence that solar facilities can be constructed and operated in a manner that also accommodates continued use of the facilities by some species of conservation concern.

Key words: endangered species, conservation, mitigation strategies, Mojave Desert, San Joaquin Desert, solar farms, species of conservation concern

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Photovoltaic solar power energy generation is expanding rapidly worldwide (REN21 2016) and particularly in California (Solar Energy Industries Association 2016). Lands with optimal conditions for the construction of utility-scale photovoltaic solar energy generation facilities (e.g., flat terrain, low-structured vegetation, high insolation rates) are abundant in California (Lovich and Ennen 2011; National Renewable Energy Laboratory 2011; Cameron et al. 2012; Stoms et al. 2013). Further incentive has been provided by bills passed by the California legislature that mandate increasing levels of energy production from renewable energy sources with the latest bill requiring that all power-supplying utilities obtain at least 60% of their electricity from such sources by 2030 and 100% by 2045 (de León 2018). As of 2019, 748 solar plants were operating in California with many more planned for construction (California Energy Commission 2020; Kern County Planning Department 2020).

The expansion of solar energy clearly is positive in many regards, particularly the associated reduction in greenhouse gas emissions compared to energy generation using fossil fuels. However, photovoltaic solar energy production can produce detrimental environmental impacts, particularly when the production facilities are constructed on natural lands. These impacts can include habitat loss, habitat fragmentation and disruption of movement corridors, direct and indirect mortality, and alteration of ecosystem processes, among others (Tsoutsos et al. 2005; Lovich and Ennen 2011; Stoms et al. 2013; Hernandez et al. 2014; Moore and Pavlik 2016; Moore-O'Leary et al. 2017). These impacts can be even more significant when species of conservation concern are potentially affected (Leitner 2009; Lovich and Ennen 2011; Moore-O'Leary et al. 2017; Boroski 2019; Phillips and Cypher 2019). We define species of conservation concern as those that are federally or state listed as endangered or threatened and California Species of Special Concern (CDFW 2020). Such species that have been affected by recent photovoltaic solar projects in California include the San Joaquin kit fox (*Vulpes macrotis mutica*; federal endangered, California threatened), giant kangaroo rat (*Dipodomys ingens*; federal endangered, California endangered), desert tortoise (*Gopherus agassizii*; federal threatened, California threatened), blunt-nosed leopard lizard (*Gambelia sila*; federal endangered, California endangered), Mohave ground squirrel (*Xerospermophilus mojavensis*; California threatened), San Joaquin antelope squirrel (*Ammospermophilus nelsoni*; California threatened), and others (Leitner 2009; Moore-O'Leary et al. 2017; Boroski 2019; Phillips and Cypher 2019).

The San Joaquin Desert region (Germano et al. 2011) has been a focal area for photovoltaic solar energy development due to an abundance of mostly flat terrain, high insolation rates, and relatively low land prices (Butterfield et al. 2013; Pearce et al. 2016; Hoffacker et al. 2017; Phillips and Cypher 2019). One of the densest concentrations of rare species in the

United States also occurs in this region (USFWS 1998; Germano et al. 2011) creating the potential for significant conflict between development and conservation (Phillips and Cypher 2019). Despite this potential, several utility-scale solar plants have been constructed in the region and more are planned (e.g., Kern County Planning Department 2020). However, a number of conservation measures have been incorporated into the design and operation of these facilities, and further conservation and planning efforts are warranted as more utility-scale photovoltaic solar plants are planned (e.g., Kern County Planning Department 2020). As a result of conservation efforts to date, most of the species of conservation concern that were present on or near individual sites prior to construction of the facilities are still present.

Our objectives in this synthesis are to (1) provide examples of species of conservation concern that are using solar facilities in the San Joaquin Desert region, (2) list the conservation measures that are facilitating continued use of the facilities by these species, (3) highlight demographic and ecological data from San Joaquin kit foxes using solar sites, and (4) discuss how the development and implementation of conservation strategies in regions outside of the San Joaquin Desert could benefit a number of other species.

SAN JOAQUIN DESERT SOLAR PROJECTS, SPECIES, AND CONSERVATION MEASURES

The San Joaquin Desert includes the arid western and southern portions of the San Joaquin Valley, the Carrizo Plain, and some smaller valleys along the eastern edge of the Coast Ranges (Fig. 1). Geographic, climatic, abiotic, and biotic attributes of this region are detailed in Germano et al. (2011). As stated previously, large portions of this region

Figure 1. Locations of seven large photovoltaic solar facilities in the San Joaquin Desert of California.

are highly suitable for solar energy development. Consequently, a number of photovoltaic solar facilities ranging from a few to hundreds of hectares have been constructed and more are planned. All of these facilities employ photovoltaic solar panels to generate electricity. Many of these facilities were constructed on lands that were in agricultural crop production up until just prior to construction. However, at least six facilities were constructed on grazing lands or natural lands that were occupied by one or more species of conservation concern (Fig. 1, Table 1).

Table 1. Species of conservation concern that use seven solar photovoltaic energy generating facilities in the San Joaquin Desert region of California. Status codes are as follows: FE = Federal Endangered; FT = Federal Threatened; CE = California Endangered; CT = California Threatened; CSSC = California Species of Special Concern.

		Solar facilities[a] (size of the facility)						
Species	Status	TSF (1902 ha)	CVSR (797 ha)	PVSF (526 ha)	CFSP (1174 ha)	LHBSF (125 ha)	WSP (567 ha)	MSSC (65 ha)
San Joaquin kit fox (*Vulpes macrotis mutica*)	FE, CT	X	X	X	X	X	X	
American badger (*Taxidea taxus*)	CSSC	X	X	X	X	X	X	X
Giant kangaroo rat (*Dipodomys ingens*)	FE, CE		X	X				
San Joaquin antelope squirrel (*Ammonspermophilus nelsoni*)	CT		X	X		X		
Swainson's hawk (*Buteo swainsoni*)	CT							X
Burrowing owl (*Athene cunicularia*)	CSSC	X	X	X	X	X	X	X
Northern harrier (*Circus hudsonius*)	CSSC							X
Loggerhead shrike (*Lanius ludovicianus*)	CSSC					X		X
Blunt-nosed leopard lizard (*Gambelia sila*)	FE, CE			X		X		
California tiger salamander (*Ambystoma californiense*)	FT, CT			X				
San Joaquin coachwhip (*Masticophis flagellum ruddocki*)	CSSC					X		
Kern mallow (*Eremalke kernensis*)	FE							X

[a] Solar facilities: TSF = Topaz Solar Farms; CVSR = California Valley Solar Ranch; PVSF = Panoche Valley Solar Farm; CFSP = California Flats Solar Project; LHBSF = Lost Hills/Blackwell Solar Facility; WSP = Wright Solar Park; MSSC = Maricopa Sun Solar Complex

Consequently, each of the solar facilities were constructed and are operated with a variety of conservation measures designed to facilitate continued occupation by the species. Some of these measures were proposed by the project proponents, some were developed by the CDFW or USFWS, and all were included as requirements in the Incidental Take Permit issued for each project under the California Endangered Species Act. The measures are numerous, and we do not provide a complete list. Instead, we focus on what we consider to be the more important measures. Two measures in particular are critically important in facilitating use of solar facilities by species of conservation concern: one is permeable security fencing, and another is the encouragement and management of vegetation within the facilities. These measures were designed to accommodate and encourage San Joaquin kit foxes, the largest of the listed species using the facilities. However, the measures also benefit most of the other species listed in Table 1, many of which have habitat requirements overlapping those of kit foxes.

At each of the facilities, the security fence surrounding the arrays of solar panels was designed to be permeable to kit foxes, as well as the smaller species of conservation concern and prey species. The fences are typically 2.4 m tall, sometimes with strands of barbed wire on the top. At most facilities, the fencing used was 5-cm mesh chain-link. To make it permeable to kit foxes, a gap of approximately 12–15 cm was left between the bottom of the fence and the ground (Fig. 2). Kit foxes can easily move through this gap. At the

Figure 2. Images of security fences that are permeable to San Joaquin kit foxes at the Topaz Solar Farms (a kit fox is visible crossing through the gap at the bottom of the fence) and California Valley Solar Ranch (a kit fox that just crossed through the fence is visible inside the facility) in San Luis Obispo County, California. (Top photo by Larry Saslaw; bottom photo by Christine Van Horn Job.)

Topaz Solar Farms (TSF), a rail was installed at the bottom of the gap to discourage larger animals from digging under the fence. At the California Valley Solar Ranch (CVSR) facility, a deer-proof style fence with 15 x 15-cm mesh openings was used (Fig. 2). All of these designs allow kit foxes and any similar sized or smaller species to pass through the fences and freely enter or exit the facilities. They also provide an added benefit in that they inhibit passage by larger species such as coyotes (*Canis latrans*) and bobcats (*Lynx rufus*), both of which are potential predators of kit foxes and many other species of conservation concern.

The other important conservation measure was that a suitable vegetation community was encouraged (Althouse and Meade, Inc. 2010; H. T. Harvey and Associates 2012) or allowed to grow in the arrays after construction was completed, and in some cases included active weed control efforts when necessary. Furthermore, vegetation structure on the facilities is managed, typically through sheep grazing (Fig. 3) sometimes supplemented with mechanical mowing within the arrays, and through cattle or sheep grazing on the buffer or conservation lands outside of the arrays. The goal is to keep the vegetation structure low (ideally ≤5 cm), which is a condition favored by kit foxes (Cypher et al. 2013), their prey, and the other species of conservation concern. Vegetation management has the additional benefit of reducing combustible fuel loads within the arrays.

In addition to permeable fencing and vegetation management, a number of other conservation measures beneficial to kit foxes and the other species also were implemented.

Figure 3. Sheep grazing at the Topaz Solar Farms (top – photo property of BHE Renewables and used with permission) and California Valley Solar Ranch (bottom – photo by Kristy Uschyk) in San Luis Obispo County, California.

Animal movement corridors were incorporated into the design of all of the facilities >500 ha in size. Instead of constructing the solar panel arrays in a single or a few large blocks, the arrays were distributed among a larger number of smaller groupings such that habitat corridors were maintained through the project sites (Fig. 4). Available information on local animal movement patterns (e.g., pronghorn [*Antilocapra americana*] and elk [*Cervus canadensis*]) and water courses were used in determining the location of corridors. Surveys

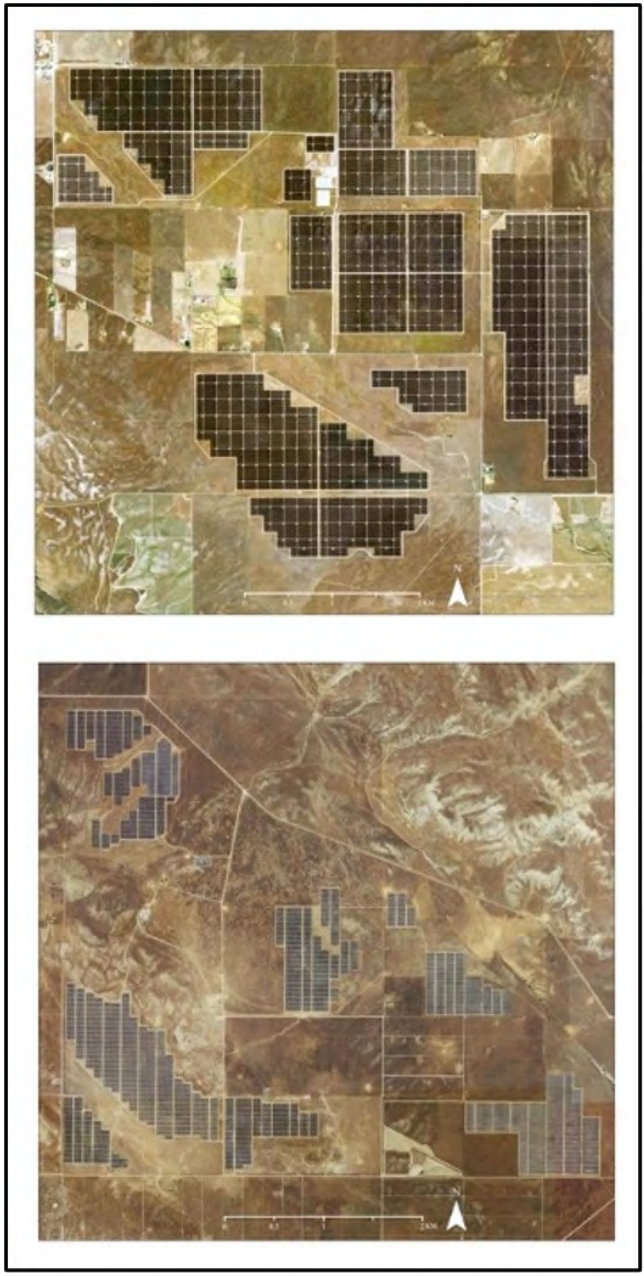

Figure 4. Google Earth images showing the wildlife movement corridors that were left open on the Topaz Solar Farms (top) and California Valley Solar Ranch (bottom) in San Luis Obispo County, California.

are conducted for dens, burrows, and signs of species presence prior to construction and prior to conducting any ground-disturbing maintenance activities. Dens and burrows that can be avoided are left intact, even if temporarily covered, to facilitate continued use after construction or maintenance activities (an approach that has been referred to as "preserve in place"). On most of the solar sites, artificial dens were created for kit foxes and even for burrowing owls on some sites. Other measures include prohibitions on pet or feral dogs and firearms, rodenticide restrictions, and trash abatement programs. Speed limits (usually 15–25 km/hr) are strictly enforced and off-road driving is restricted. Hazardous substance spills are rapidly cleaned up. Another common measure is that employees, contractors, and others working outdoors at the facilities are required to complete an environmental awareness program including recognition of the species of conservation concern and required actions if a species is observed. Finally, "designated biologists" provide input on activities that potentially could cause harm to species of conservation concern and are present on-site under some circumstances to assist with implementing avoidance measures.

SAN JOAQUIN KIT FOXES USING SOLAR FACILITIES

We highlight the San Joaquin kit fox as an example of a species using photovoltaic solar facilities in the San Joaquin Desert region because (1) it has been documented using at least six of the facilities in Table 1, (2) it is a high-profile, highly charismatic species that draws lots of attention from the public and conservation groups, (3) many of the conservation measures implemented for species on the facilities were designed primarily to benefit kit foxes although other species commonly benefit from the measures as well, and (4) considerable demographic and ecological data have been collected on kit foxes using solar facilities. Kit foxes are resident on some of the larger facilities (e.g., TSF, CVSR, Panoche Valley Solar Farm [PVSF], California Flats Solar Project [CFSP] in Table 1) and use some smaller facilities to varying degrees. At the TSF, CVSR, and PVSF facilities, 3-year post-construction studies were a requirement in the Incidental Take Permits issued by the CDFW for the construction and operation of those facilities. These studies entailed quantifying demographic and ecological attributes of kit foxes on the solar facilities (i.e., "solar sites") and comparing them to attributes of foxes using nearby undeveloped control areas (i.e., "reference sites"). The TSF and CVSR studies were completed in 2017 (Cypher et al. 2019b; H. T. Harvey and Associates 2019), while the PVSF study was initiated in May 2019 and will be completed in June 2022 (Endangered Species Recovery Program [ESRP] unpublished data). A similar study was not required at the CFSP, but an opportunistic research effort on kit foxes was initiated at that facility in November 2020 (ESRP unpublished data).

Much of the demographic and ecological information presented below is from the TSF and CVSR facilities, supplemented with preliminary information from the PVSF facility. In Table 2, we compare values for various demographic and ecological attributes between solar sites and associated reference sites. To provide further perspective, in Table 3 we compare the ranges of values from the solar sites to ranges from studies on non-solar sites in kit fox population core areas where habitat conditions are most optimal (Cypher et al. 2013).

Demographic Attributes

Annual survival probabilities of adult kit foxes were not statistically different between solar and reference sites (Table 2). Indeed, on the TSF and CVSR sites, survival probabilities consistently trended higher on the solar sites compared to the reference sites (Cypher

Table 2. Comparison of demographic and ecological values for San Joaquin kit foxes on solar sites and associated reference sites in the San Joaquin Desert region, California. Solar sites: TSF = Topaz Solar Farms (2014–17); CVSR = California Valley Solar Ranch (2014–17); PVSF = Panoche Valley Solar Farm (2019–20). See text for detailed definitions of the attributes. Data sources: TSF – Cypher et al. 2019b; CVSR – H. T. Harvey and Associates 2019; PVSF – ESRP unpublished data.

Kit fox attribute	Solar site	Reference site
Probability of survival		
TSF	0.65	0.49
CVSR	0.76	0.66
PVSF	0.84	1.0
Reproductive success (%)		
TSF	100	88.9
CVSR	86.7	86.7
PVSF	100	100
Mean litter size (range)		
TSF	4.3 (2–8)	3.9 (1–7)
CVSR	3.2 (1–5)	4.5 (2–7)
PVSF	4.7 (4–5)	5.4 (4–7)
Mean mass (kg) – Males		
TSF	2.48	2.64
CVSR	2.69	2.53
PVSF	2.72	2.66
Mean mass (kg) – Females		
TSF	2.16	2.16
CVSR	2.22	2.15
PVSF	2.16	2.15
95% MCP home range (km^2)		
TSF	9.4	5.1
CVSR	3.9	4.2
PVSF	8.1	1.8
Mean dens per fox		
TSF	11.2	8.4
CVSR	15.1	19.4

et al. 2019b; H. T. Harvey and Associates 2019). The survival values from the solar sites clearly fell within the upper half of the range of values from non-solar study areas (Table 3). Lower survival values would have been expected if the solar facilities were having a detrimental effect on kit foxes. Instead, the facilities may have provided some benefits that enhanced survival. As described previously, the security fences surrounding the solar arrays inhibited entry by larger predators that commonly are the primary source of mortality for kit foxes (Cypher 2003). Furthermore, the panels also may have provided protection from

Table 3. Comparison of demographic and ecological values for San Joaquin kit foxes on solar and non-solar sites in population core area in the San Joaquin Desert region, California. Solar sites: TSF = Topaz Solar Farms (2014–17); CVSR = California Valley Solar Ranch (2014–17); PVSF = Panoche Valley Solar Farm (2019–20). See text for detailed definitions of the attributes.

Kit fox attribute	Solar sites	Non-solar sites
Probability of survival	0.65 – 0.84	0.38 – 1.0
Reproductive success (%)	86.7 – 100	0 – 100
Mean litter size (range)	3.2 – 4.7	2.0 – 5.4
Litter size range	1 – 8	1 – 9
Mean mass (kg) – Males	2.48 – 2.72	2.33 – 2.66
Mean mass (kg) – Females	2.16 – 2.22	2.15 – 2.16
95% MCP home range (km^2)	3.9 – 9.4	1.3 – 11.4
Mean dens per fox	11.2 – 15.1	8.4 – 19.4

[a] Data sources for solar sites: Cypher et al. 2019b, H. T. Harvey and Associates 2019, ESRP unpublished data.

[b] Data sources for non-solar sites: Cypher et al. 2000, 2009, 2014, 2019b; ESRP unpublished data; H. T. Harvey and Associates 2019; Koopman et al. 1998; Nelson et al. 2007; Ralls and White 1995; Spiegel 1996, unpublished data; Warrick and Cypher 1999; White and Ralls 1993; Zoellick et al. 2002.

aerial predators, particularly golden eagles (*Aquila chrysaetos*), which can cause significant mortality (Cypher et al. 2019a,b). Thus, the arrays may have provided somewhat of a refuge effect. Finally, predators were the primary cause of mortality among kit foxes using solar facilities (with most deaths occurring outside of the fenced arrays), similar to that on the reference and other study sites (Cypher et al. 2019b; H. T. Harvey and Associates 2019). No kit fox mortalities associated with construction or operation (e.g., collision with vehicles or equipment, entombment, electrocution, etc.) of the various solar sites have been reported.

For kit foxes, a female or mated pair commonly is considered to have successfully reproduced if pups are observed at a den of the female or pair. Reproductive success did not differ between solar and reference sites (Table 2) and in most cases was identical. As with survival, reproductive success values were in the upper range of values reported from other studies (Table 3). Mean litter size also did not differ statistically between solar and reference sites (Cypher et al. 2019b; H. T. Harvey and Associates 2019; ESRP, unpublished data) and the range of litter sizes was similar as well (Table 2). The values from the solar sites were well within the range of values reported from core population areas (Table 3).

Mean mass values also did not differ statistically between solar and reference sites (Table 2; Cypher et al. 2019b; H. T. Harvey and Associates 2019; ESRP, unpublished data). Mean mass would be expected to be lower on sites if foxes were having difficulty finding enough food to maintain weight. Indeed, in comparison with results from other studies (Table 3), the mean values for males on the PVSF and females on the CVSR were the highest recorded.

Ecological Attributes

Home range size was one attribute that did differ significantly between solar and reference sites, although the pattern differed among facilities (Table 2). At the TSF and PVSP,

mean home range size was significantly larger on the solar sites compared to the reference sites (Cypher et al. 2019b; ESRP, unpublished data). However, at CVSR, mean home range size was similar to that on the reference site (H. T. Harvey and Associates 2019). Home range size among foxes commonly is inversely related to habitat quality, particularly food availability (Macdonald 1981; Fuller and Sievert 2001; Macdonald et al. 2004). On the TSF and PVSP facilities, prey availability actually may have been lower compared to the associated reference sites (Cypher et al. 2019b; ESRP, unpublished data). The TSF was built primarily on lands that had been in active agriculture just prior to construction. Agricultural activities significantly suppressed, if not excluded, most kit fox prey. Thus, potential prey, particularly nocturnal rodents such as kangaroo rats, were in early stages of recovery on the solar site when the home range work was being conducted (Cypher et al. 2019b). The PVSP facility was constructed on lower quality habitat compared with the associated reference site where kangaroo rats occurred in much higher numbers (Center for Natural Lands Management, unpublished data). Disturbance during facility construction also may have depressed the abundance of any prey present on both the TSF and PVSP facilities. Thus, although prey likely will increase with time on both sites, lower prey abundance during the kit fox home range work likely contributed to larger home ranges on the solar sites.

The CVSR was constructed on lands that were largely intact and that supported large numbers of giant kangaroo rats. Measures were taken during construction to limit habitat impacts and avoid population concentrations. Due to high abundance, it was still necessary to relocate 225 giant kangaroo rats outside of solar facility construction areas (H. T. Harvey and Associates 2013). Giant kangaroo rats then quickly began recolonizing the array areas once construction was completed and now number in the thousands (H. T. Harvey and Associates, unpublished data). This high prey abundance, possibly along with protection from predators provided by the arrays, resulted in mean kit fox home range size being similar between the solar and reference sites (Table 2). Although kit fox home ranges trended larger on some of the solar sites, they were still within the range of mean home range sizes reported from other studies in core population areas (Table 3).

Kit foxes exhibit obligate use of subterranean dens (Grinnell et al. 1937). Kit foxes along with closely related swift foxes (*V. velox*) are unique among North American canids in using dens daily throughout the year (Cypher 2003). Dens are used not only for rearing young, but also for diurnal resting, predator avoidance, thermoregulation, and water conservation (Koopman et al. 1998). Consequently, kit foxes annually use multiple dens, which are dispersed throughout each individual's home range. Unusually low numbers of dens used by individual foxes could indicate low den availability while unusually high numbers could indicate high levels of disturbance or even destruction of dens causing foxes to have to find new ones. However, the mean number of dens used per fox was not statistically different between solar and reference sites (Table 2). The values for the solar sites were within the range of values reported from other studies in the core population areas (Table 3).

Finally, foxes on solar sites primarily consumed heteromyid rodents, particularly kangaroo rats, and invertebrates. Food item selection by kit foxes using solar sites was similar to that on reference sites as well as that by kit foxes in other core population area study sites (Cypher et al. 2019b; H. T. Harvey and Associates 2019).

In summary, assisted by the conservation measures that were implemented, kit foxes are present and persist on several solar facilities in the San Joaquin Desert. Demographic and ecological data collected to date at three sites indicate the kit foxes are functioning in a

manner similar to foxes on nearby reference sites (Table 1). Clearly, solar facilities of any size can be constructed and operated in a manner that is compatible with continued use by kit foxes. Furthermore, although intensive quantitative studies similar to those for kit foxes have not been conducted for other species, a number of other species of conservation concern also have been documented as resident on or at least occasionally using solar facilities (Table 1). As with kit foxes, these species undoubtedly benefit from the conservation measures implemented at the facilities, including the potential refugium effect afforded by the fenced arrays and vegetation management. Furthermore, the solar farms might even enhance regional carrying capacity when constructed on marginal habitat such as dryland agricultural lands or even many grazing lands where the common use of rodenticides and other practices can be detrimental to species. As an example, the CFSP facility was constructed in an area with suboptimal habitat for kit foxes, and foxes were present in low abundance in a limited area prior to construction. Now that construction is complete, foxes occur in greater abundance and are distributed throughout the facility (Althouse and Meade, Inc., unpublished data).

SPECIES AND SOLAR FACILITIES IN OTHER REGIONS

The findings above have implications that potentially extend beyond the San Joaquin Desert region. Numerous photovoltaic solar facilities also are being constructed in the Mojave Desert and other regions in California and throughout the western United States, and these facilities have the potential to impact other rare species (Leitner 2009; Lovich and Ennen 2011; National Renewable Energy Laboratory 2011; Cameron et al. 2012; Moore-O'Leary et al. 2017; Boroski 2019). These facilities are being constructed on thousands of hectares of habitat and the potential for further habitat impacts is considerable. In the Desert Renewable Energy Conservation Plan (DRECP) for the Mojave Desert (BLM 2016), approximately 130,000 ha within "Development Focus Areas" have been identified as being potentially suitable for solar facilities. This total just includes BLM lands and does not include other public or private lands that also might be suitable for the construction of solar facilities.

The DRECP also identifies 39 animal and plant species of conservation concern that potentially could be impacted by development of habitat in the Mojave Desert (BLM 2015). Of these 39 species, 22 are Federal or State listed as Endangered or Threatened. Current policy and practices at photovoltaic solar facilities in the Mojave typically entail actively or passively translocating species of conservation concern off facility construction sites and then using exclusionary fencing to prevent those species from returning, even once construction has been completed. Reduction or elimination of natural vegetation on sites further discourages species from returning. (For examples of typical practices currently implemented or proposed for photovoltaic solar sites in the Mojave Desert of California, see USFWS 2014; BLM 2019; ECORP Consulting, Inc. 2019; Michael Baker International 2019).

Translocation during construction can be an important avoidance and minimization strategy, but exclusion can increase local habitat loss, fragmentation, and loss of demographic and genetic connectivity. Also, survival of translocated individuals not uncommonly is low, particularly when "hard release" strategies are used in which translocated individuals are immediately liberated at the release site (e.g., Chipman et al. 2008; Germano 2010; Hamilton et al. 2010; Scrivner et al. 2016; Mengak 2018). Furthermore, residents in the areas where translocated individuals are released also could be adversely affected through increased competition (particularly if the resident population is already at carrying capacity), crowding stress, disruption of social units, and introduction of disease (e.g., Griffith and Scott 1993;

Chipman et al. 2008; Shier and Swaisgood 2012; Mengak 2018).

The DRECP list of species that potentially could be affected by solar facilities includes a number of species that occur in the arid, sparsely vegetated, relatively flat areas (that are optimal for solar energy development) with ecological requirements that are similar to those of San Joaquin Desert species. These species include Agassiz's desert tortoise, flat-tailed horned lizard (*Phrynosoma mcallii*), Mojave fringe-toed lizard (*Uma scoparia*), burrowing owl, Mohave ground squirrel, desert kit fox (*Vulpes macrotis arsipus*), and a number of the plant species. These species conceivably could occupy and use solar facilities if conservation measures similar to those implemented on the San Joaquin Desert facilities (e.g., permeable fencing, vegetation management, artificial burrows, speed limits, etc.) were implemented on the Mojave Desert facilities. Other species with different ecological requirements also might be accommodated with these or alternative conservation measures.

A critical need is to identify and evaluate potential conservation strategies and specific measures that could facilitate use of photovoltaic solar facilities by species of conservation concern in the Mojave Desert and other regions. This process is likely to require some years, as it did in the San Joaquin Desert. This effort is vital to verify that species can indeed use solar facilities as well as to identify the most efficacious approaches. Any such effort obviously would be facilitated by a collaborative relationship between solar developers and natural resource agencies. Indeed, such an effort is in progress near Pahrump, Nevada. In collaboration with the U.S. Fish and Wildlife Service and the University of Nevada, the Valley Electric Association (VEA) teamed with Bombard Renewable Energy to construct a 32-ha wildlife-friendly demonstration facility called the Community Solar Project (VEA 2020). Conservation measures implemented at this facility included minimizing vegetation disturbance during construction, planting native shrub seedlings, seeding some areas with a native seed mix, and installing 25x18-cm openings at 80-m intervals along the base of the security fence. Extensive monitoring is being conducted and desert tortoises (as well as desert kit foxes, rattlesnakes, rabbits, and other species) are commonly passing through the fence and the using the habitat on the facility. Plants favorable to desert tortoises and other wildlife appear to be thriving in the microclimate created by the solar panels (VEA 2020).

The U.S. Fish and Wildlife Service and California Department of Fish and Game have statutory requirements related to take that must be met. The California Endangered Species Act requires that "take must be minimized and fully mitigated" (Fish & G. Code §2081(b); Cal. Code Regs., tit. 14, §§783.2–783.8) and the federal Endangered Species Act requires that "the applicant must to the maximum extent practicable, minimize and mitigate the impacts of take" (50 C.F.R. §17.22(b)(2)). To fulfill these requirements, solar facility developers commonly purchase off-site conservation lands to mitigate the impacts of their facilities to species of conservation concern and also provide funds for the long-term management of these lands. These costs are substantial. This understandably reduces enthusiasm for also incurring the additional costs of implementing on-site conservation measures, the cost for which also could be substantial over a 30-year facility operational period.

Another concern is that if species inhabit or occasionally use solar facilities, there is a risk of accidental injury or death from operations and maintenance activities. With the implementation of appropriate conservation measures this risk would be low, and if the conservation measures were designed to enhance reproduction and survival, then this could easily compensate for incidental losses. Indeed, to date, mortalities of individuals of species of conservation concern on the San Joaquin Desert solar facilities have been ex-

tremely rare. Furthermore, even a low number of occasional mortalities would still result in larger overall populations of species. For example, if solar facilities could support 1,000 individuals of a species, translocation and exclusion could result in the loss of a proportion of those individuals, given the lower survival of translocated individuals and adverse effects on residents in release sites, as discussed previously. However, if the species was allowed to continue to occupy the solar facility and even if 5% of the individuals died annually due to maintenance and operation activities (given the results from the San Joaquin Desert facilities, a 5% annual rate would be rather high and therefore unlikely), that would still leave 950 individuals, which likely is a higher survival rate than would be realized if the 1,000 individuals were translocated. Also, continued occupation of the facilities would reduce habitat fragmentation effects and help maintain connectivity.

Identifying conservation approaches that benefit species of conservation concern on photovoltaic solar facilities, meet regulatory requirements, and are cost effective will be challenging. This will require some time and testing, and efforts will benefit from collaboration between solar developers, natural resource agencies, researchers, and others. We only address photovoltaic facilities, but similar conservation measures may be possible at other types of facilities as well (e.g., power tower, solar thermal). The successes realized in the San Joaquin Desert as well as early results from the VEA demonstration facility in the Mojave Desert suggest that the conservation outcomes can be worth the investment. These efforts should be built upon, improved, and then widely implemented so that we can have renewable electricity and our species, too.

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FULL RESEARCH ARTICLE

Factors influencing the abundance of wintering western snowy plovers at Crown Memorial State Beach

DAVID L. RIENSCHE*

East Bay Regional Park District, 2950 Peralta Oaks Ct, Oakland, CA 94605, USA

* *Corresponding Author: driensche@ebparks.org*

Survival during the nonbreeding season, when mortality from food shortages and raptor predation is highest, influences shorebird population growth. These selection pressures, as well as anthropogenic influences, can shape wintering shorebird habitat use patterns. The western snowy plover (*Charadrius alexandrinus nivosus*) is a small shorebird that uses sand-spits, dune-backed beaches, open areas around estuaries for foraging and roosting. The Pacific Coast population of western snowy plovers is listed as a federally threatened species and a California Species of Special Concern. Previous studies suggest humans, dogs and corvids are sources of disturbance to plovers on public beaches. During 2014 to 2019, these disturbance factors were examined at Robert W. Crown Memorial State Beach in Alameda, California. In decreasing order of impact, the beach using public, corvids, and dogs were found to be the major stressors to over wintering plovers. Both the public and corvids respectively, resulted in disturbance and avoidance behaviors by plovers nearly 40% of the time. In 2015, the District created the Plover Protection Zone (PPZ) by installing symbolic fencing, signage, and establishing a volunteer team to monitor plovers and educate the public. In 2016, the potential prey abundance within the plover protection zone and areas directly north and south were examined using core samples and sticky traps. Statistical analysis showed a significant difference in the amount of macro-invertebrate prey available in the area used by the plovers as compared to other locations. Habitat choice and prey availability are vital to wintering shorebird. During this study, the wintering population of western snowy plovers increased from six to over 54 individuals.

Key words: *Charadrius nivosus nivosus*, dogs, human recreation, invertebrate prey, management actions**,** western snowy plover

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The western snowy plover *(Charadrius nivosus nivosus)* is a small light grayish-brown shorebird with black legs and bill, that wears an incomplete dark breast band (Cogswell 1977). The western snowy plover is federally listed as threatened and is a California Spe-

cies of Special Concern (USFWS 2012; CDFW 2019). Reasons for federal listing include poor productivity, low survival rates (USFWS 1993, 2007), increasing predation (Neuman et al. 2004), human disturbance (Ruhlen et al. 2003; Lafferty et al. 2006), loss of habitat due to development, exotic vegetation, and human recreational activities (Page and Stenzel 1981; USFWS 2007; Muir and Colwell 2010). The Pacific Coast population of the western snowy plover range extends from Damon Point, Washington, USA to Bahia Magdalena, Baja California, Mexico (Page et al. 1995; USFWS 2007). This special status species is dispersed along the coastline with an estimated breeding population of 2,500 individuals (USFWS 2012) and the wintering number of plovers in California varies among sites (Page et al. 1986).

Many shorebird populations are declining worldwide (Helmers 1992; Morrison et al. 2006; Delaney et al. 2009; Rosenberg et al. 2019) and the choice of wintering locations plays a vital role in their survival and population growth (Brindock and Colwell 2011). Causes of mortality for wintering shorebirds include food shortages and predation by raptors (Page and Whitacre 1975; Evans and Pienkowski 1984; Cresswell and Quinn 2004). Human activity can mimic raptor predation, causing shorebirds to vacate sites and spend more energy on vigilance and escape, where anthropogenic disturbances are chronic and intense (Pfister et al. 1992; Kirby et al. 1993). Burger (1981) reported that shorebirds show the greatest avoidance to people, and due to this vulnerability, human activity should be restricted around shorebird areas. Lastly, plover populations worldwide occupy habitats favored by humans for recreation (Weston 2019) and studies suggest that human disturbance can limit plover population size and reduces habitat quality.

The piping plover *(Charadrius melodus)* found along the Atlantic and Gulf coasts of the United States is similar in size to the western snowy plover. During the winter, piping plovers search for sustenance amidst sandflats, ponds, and shorelines. Their foraging efficiency can affect the fat reserves needed for migration and reproduction (Evans 1976; Burger 1994). Studies indicate that piping plover in high human disturbance areas have lower reproductive success due to reduced foraging efficiency and depleted fat reserves (Burger 1986, 1991, 1994; Flemming et al. 1988; Staine and Burger 1994). Likewise, for another closely related plover, food abundance is known to influence habitat selection by the semipalmated plover (*Charadrius semipalmatus)* (Rose and Nol 2010). Additionally, Brindock and Colwell (2011) concluded that western snowy plovers select habitats with greater food availability and where they can more easily detect predators during the nonbreeding season. They recommend maintaining habitat with attributes that support abundant food and reduce predation risks (i.e., limit obstructive cover) that may be important to individual survival and maintaining the Pacific Coast population of snowy plovers.

Western snowy plovers have wintered on San Francisco Bay since the late 1800s (Page et al. 1986). Along Alameda's South Shore (also known as Robert W. Crown Memorial State Beach) Page et al. (1986) reported a high count of 58 western snowy plovers; however, in recent decades this species has not been recorded with any regularity and presumed absent. During the winter of 2014, a small population of western snowy plovers overwintered along a specific stretch of sand at Robert W. Crown Memorial State Beach. The purpose of this study was three-fold. First, to understand human impacts and other disturbance factors effecting western snowy plovers abundance on a public beach; second, how to restrict public access to the plovers roosting and foraging habitat by establishing a Plover Protection Zone (PPZ; a roped-off area composed of symbolic fencing and signage) adjacent to the beach; and finally, to examine the potential prey availability within the PPZ and in the areas to the north and south.

METHODS

Study Area

The study took place at Robert W. Crown Memorial State Beach (37.76034N, 122.26661W) a 3.2-km sandy beach, located on the east side of San Francisco Bay in the city of Alameda. The site is managed by the East Bay Regional Park District (EBRPD).

Sampling Methods

From 2014 through 2019, I surveyed the site 610 times for western snowy plovers between the hours of dawn and dusk, amassing a total of 587 observational hours. These monitoring periods ranged from 0.5 to 2 hours (averaging 1 hr., due to weather and tide events) and were conducted from a distance greater than 30 m to avoid disturbance to birds. The plovers typically roosted in one or two small clusters along the same stretch of dry sand near the northern end of Robert W. Crown Memorial State Beach. I used binoculars and a spotting scope to detect plover behavior. Disturbance factors (beach using public, corvids, dogs) were recorded when entering or flying over the PPZ. The time, type of disturbance factor, number, behavior, and direction from/to were recorded, as well as the plovers' pre-disturbance behavior and post-disturbance reaction (if any). Plover post-disturbance reactions were classified as: no reaction, run and return to previous behavior, fly up and return to previous behavior, fly away and no return, or other.

I performed invertebrate sampling from December 2016 to February 2017 during daylight (0700 – 1430 PST). A 50-m horizontal transect was placed along the wrackline within, north and south of the PPZ. I collected GPS coordinates using a Garmin GPS eTrex 10 along a 50-m transects. Random numbers (between the integers of 0-50) were generated and assigned to three sticky trap sampling locations and five core sampling points. An aluminum Danielson clam gun, marked a 10-cm depth, was used to obtain macro-invertebrate prey availability core sampling along the horizontal transect within the PPZ, and directly north and south. Five vertical transects 5-m in length were distributed along the horizontal transects. I collected in the center, 2.5-m above and below the wrackline. The wrack was moved aside before collecting core sampling. The forty-five core samples were processed and sorted daily. Additionally, I placed sticky traps in horizontal and vertical orientations near the wrackline following methods in Anteau and Sherfy (2010). Setups were left undisturbed for approximately 1 hour (Pearl 2015). The sticky traps were monitored during core sampling to minimize disturbances. After an hour, I placed each sticky trap setups into its own separate plastic bag for further analysis. Macro-invertebrates obtained in both sticky traps and core sampling were brought into the lab where organisms were then identified to their respective taxa under a Nikon SMZ800 microscope. All field work was completed in accordance with the terms and conditions of USFW TE-817400-12 Recovery Permit and CDFW SCP-002298.

Statistical Analyses

A series of statistical analysis were run for the disturbance factors and for the potential prey availability within the Plover Protection Zone (PPZ) for Western Snowy Plover, with a finding of significance set at ($\alpha = 0.10$) for disturbance factors and ($\alpha = 0.05$) for potential prey availability. The Microsoft Excel® (2016) Chi-Square test was run to compare

the disturbance factors (beach using public, crows/ravens, and dogs) that may be affecting overwintering Western Snowy Plovers. To compare the change in population of over wintering plovers, following the construction of the PPZ in 2014 through 2019 an R^2 value was obtained using IBM SPSS® Statistics 23 (2018). To test the hypothesis's that there was no significant difference in macro-invertebrate prey abundance (core samples or in sticky traps) within the PPZ and in the areas directly north and south a Chi-Square tests was done using (R Core Team®, 2019).

RESULTS

During the survey effort 6,728 beach using public, I recorded 740 corvids, and 86 dogs within the study area. Human presence was nearly constant, while corvid numbers varied during the study. Western snowy plovers were typically engaged in roosting (80%) and foraging (20%) behavior prior to a disturbance event (Table 1). These plovers showed moderately negative responses to the presence of both beach using public and hunting crows/ravens (Table 1), by displaying "run & return", "fly & return" and "fly away" responses cumulatively in 80 % of the observations, respectively. For the beach using public, the plover "run and return" disturbance response was the most recorded during 26% of the observations (Table 1). Plovers had a statically significant ($P < 0.10$) negative response to the presence of dogs, at 80% of the time, with their typical response being the "run and return" (Table 1).

Table 1. Western snowy plover (WSNP) behavior prior to and following disturbance by beach using public, hunting crows and ravens (corvids), and dogs (on or off leash) at Robert W. Crown Memorial State Beach from 2014–2019.

WSNP Behavior	Roosting	Foraging	No Reaction	Run & Return	Fly & Return	Fly Away
Prior to Disturbance	80%	20%	n/a	n/a	n/a	n/a
Response to beach using public	n/a	n/a	64%	26%	8%	2%
Response to hunting corvids	n/a	n/a	60%	22%	12%	6%
Response to dogs	n/a	n/a	20%	60%	11%	9%

The potential macro-invertebrate prey abundance within the PPZ, and in areas directly north and south resulted in a total of 71 organisms found in the core samples and a total of 533 organism caught in sticky traps. The total number of macro-invertebrate prey items in the core samples within the PPZ was significantly higher ($P < 0.05$) as compared to the areas directly north and south (Fig. 1). The total number of macro-invertebrate prey items in the sticky traps within the PPZ was significantly higher ($P < 0.05$) as compared to the areas directly north and south (Fig. 2). Continued analysis of the potential prey items found in the core samples and sticky traps within the PPZ showed that amphipods (*Megalorchestia* sp.) and flies (Order Diptera) were significantly more abundant ($P < 0.05$) as compared to the areas directly north and south (Fig. 3) and (Fig. 4) respectively. Lastly, the overwintering population of Western Snowy Plovers showed significantly increased ($R^2 = 0.96$) from 6 to over 54 individuals with the establishment and management of the PPZ at Robert W. Crown Memorial State Beach (Fig. 5).

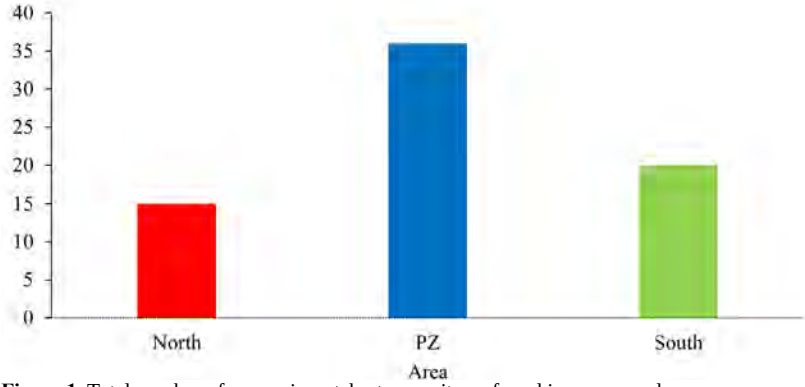

Figure 1. Total number of macro-invertebrate prey items found in core samples.

Figure 2. Total number of macro-invertebrate prey items found in Sticky Trap samples.

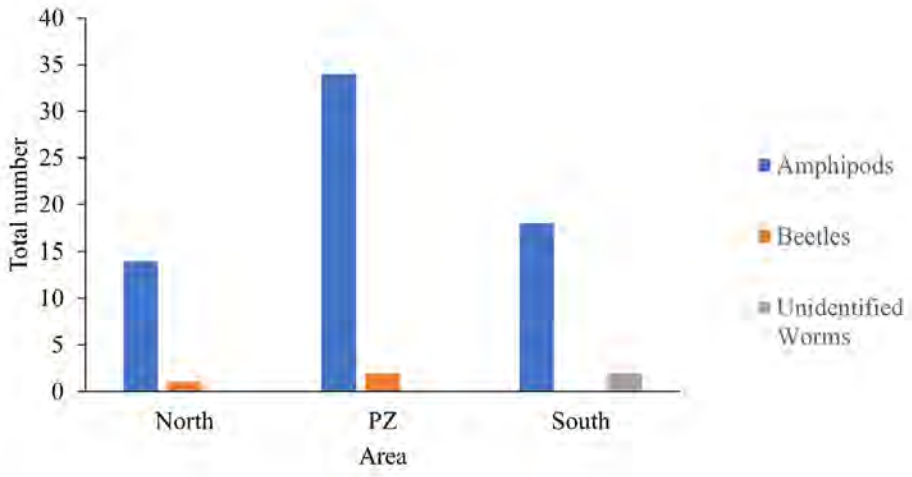

Figure 3. The potential prey items found in the core samples.

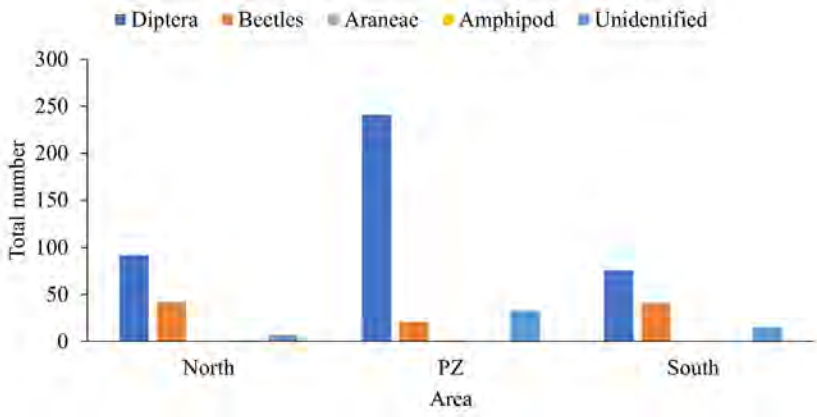

Figure 4. The potential prey items found in the Sticky Trap samples.

Figure 5. The western snowy plover (WSNP) population trend at Robert Crown Beach State Memorial Park in Alameda, CA, from 2014–2019.

DISCUSSION

The potential impacts that human disturbance may have on bird populations is a broadly studied issue in conservation biology (Stalmaster and Newman 1978; Belanger and Bedard 1989; Pfister et al.1992; Reijen et al. 1995; Gill 1996). Many studies show that birds avoid areas where humans are present (Stalmaster and Newman 1978; Burger 1981; Tuite et al. 1984; Klein et al. 1995; Reijen et al. 1995). Many shorebirds use sandy beaches and are subject to disturbances by humans and domestic pets that can reduce their resting and foraging opportunities (Brown et al. 2000). Thus, the U.S. Shorebird Conservation Plan requests more information to determine how disturbances affect shorebird populations so that managed areas can be used for educational and outdoor recreational activities that also support conservation recovery goals (Brown et al. 2001).

Species with little suitable habitat available elsewhere cannot show marked avoidance of disturbance factors even if their fitness costs are high (Gill et al. 2001), whereas species with many alternative sites to move to are likely to avoid disturbances even if the fitness costs are low. For example, Webber et al. (2013) reported that snowy plover site occupancy and colonization in the Florida Panhandle was negatively associated with human disturbance and site extinction was positively associated with these human disturbances. In southern California, where levels of human disturbance are also high, the management of this factor led to an increase in western snowy plover abundance during the nonbreeding season and ultimately the reestablishment of breeding plovers after a 30-year absence (Lafferty et al. 2006). At Robert W. Crown Memorial State Beach, the establishment of symbolic fencing, signage, and volunteers to conduct plover monitoring and public education produced positive results leading to a nearly ten-fold increase in wintering western snowy plovers over a six-year period.

Many wildlife species view dogs as a threat and both unleashed and leashed dogs can have an adverse impact displacing native birds from natural areas (Banks and Bryant 2007). Dogs are known to negatively impact special status species by disrupting their behavior, usage of preferred habitat, affecting their survival rates and reproductive success which contributes to the species population decline (Purdy et al. 1987; Weston et al. 2014). For example, Lafferty (2001) reported that off leash dogs on the beach were a disproportionate source of disturbance and that wintering western snowy plovers were more likely to fly away from dogs than humans. Results obtained at Robert W. Crown Memorial State Beach showed that leashed and unleashed dogs caused negative reactions to western snowy plovers 80% of the time with the plovers' primary response being "running and returning to their previous behavior" (60% of the time) after the dog was no longer visible. Plovers at this site also showed avoidance behaviors to crows and ravens as corvids are known to predate plover eggs and chicks (Lafferty 2001).

For shorebirds, food availability is an important site selection factor (Brindock and Colwell 2011; Evans 1976). Brindock and Colwell (2011) reported that western snowy plovers, during the non-breeding season chose sites with a higher abundance of brown macroalgae and associated invertebrates such as flies and amphipods. We know from Beeler (2009) that the amount and type of wrack (macroalgae) as well as the abundance of invertebrates can change daily due to storms and other influences. Additionally, plover invertebrate prey items may be found at a range of depths (Nicholls and Baldassarre 1990; Beeler 2009; David Orluck, Humboldt State University, personal communication). Amphipods and flies are both considered major food items for western snowy plovers (Page et al. 1995) and were significantly positively correlated with the presence of plovers along distinct stretches of Robert W. Crown Memorial State Beach. The amount of macro-invertebrate prey (amphipods and flies) available in the PPZ was significantly higher than in the areas directly north and south. It is highly plausible that prey availability is one of the strong factors for plovers selecting this area to overwinter at Robert W. Crown Memorial State Beach. This is consistent with Clark et al. (1993) findings in that plovers select habitat with high food availability and low risk of predation, emphasizing the importance of food on the winter distribution of shorebirds.

Plovers frequently feed on terrestrial insects that cluster around the wrack line where human traffic can disturb foraging plovers (Burger 1994). In this study, it was observed that when foraging plovers were interrupted by human activities, they would stop feeding and move away from the wrack and stand until the disturbance disappeared. Short escape flights are energetically costly to small birds like plovers (Nudds and Bryant 2000). If a plover

spends significant time avoiding disturbances, it may not be able to dedicate enough time to efficiently find food regardless of invertebrate prey availability (Weston and Elgar 2005) and thus may limit plover survival and population growth (Yasue and Dearden 2006). As Lafferty (2001) inferred few human activities are lethal to roosting plovers. Those impacts can instead be understood by how human disturbances reduce plover foraging and roosting opportunities that can lead to cumulative effects that lower adult survivorship and reproductive potential.

Habitat factors and conditions such as food availability and disturbance are especially critical for shorebird conservation and management when we consider that roughly 50% of North America's shorebirds are declining and that habitat loss is the leading cause of endangerment of bird species in the United States (Brown et al. 2001; Johnson 2007). This study demonstrates the need to actively manage refuges to reduce disturbance to wintering western snowy plovers. This research showed that plovers are wary of both humans and corvids, with their strongest response to canine owners violating the no-dogs-on-the-beach ordinance. These results complement the findings of Lafferty (2001) in that humans, dogs and crows were the main sources of disturbance to wintering western snowy plovers on public beaches. Likewise, the macro-invertebrate prey analysis supported those of Brindock and Colwell (2011) and Evans (1976) in that food availability is an important influence for habitat selection by plovers. Western snowy plovers overwintering at Robert W. Crown Memorial State Beach habitually used the same stretch of sand during the course of this six-year study. These birds have few alternative roosting sites due to their site fidelity and narrow habitat selection requirements (Lafferty 2001). Lastly, by implementing management actions that decreased human disturbance, such as symbolic fencing (also known as, seasonal fencing; Webber et al. 2013) to dissuade public access at this location led to a nearly ten-fold increase in wintering western snowy plovers. Symbolic fencing is a visual barrier (which may include signage) and consists of removable narrow poles with line running through a hole at the top to make people walk around areas where it may be difficult to see roosting shorebirds.

The anthropogenic change taking place along California's coastline, coupled with rising sea levels and climate change, will intensify the inherent conflicts between humans engaging in certain outdoor recreation and shorebird populations, because both depend on a very narrow strip of sand. In the short term, the most sensible approach may be to concentrate research and protection efforts on threatened species whose populations are declining, and for which human disturbance is implicated as a contributing factor (Gill et al. 2001). Additional research efforts on this topic may consider examining how dune shape, beach debris, the establishment of resource protection areas (PPZ), and access to low and high-energy foraging areas influence overwintering western snowy plover site occupancy and colonization.

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FULL RESEARCH ARTICLE

Environmental values of California winegrape growers and the use of barn owl nest boxes as a tool for integrated pest management

BROOKS R. ESTES[1*] AND MATTHEW D. JOHNSON[2]

[1] *Humboldt State University, Environment & Community Program, 1 Harpst Street, Arcata, CA 95521, USA*

[2] *Humboldt State University, Wildlife Department, 1 Harpst Street, Arcata, CA 95521, USA*
**Corresponding Author: phoenix.leo@gmail.com*

Synthetic pesticides from agriculture pose threats to biodiversity, and the adoption of alternative pest management is vital to meet rising crop demands while protecting native species. For example, the use of nest boxes for barn owls (*Tyto furcata* and *T. alba*) may help control rodent pests and reduce the use of rodenticides. However, the environmental perceptions of farmers and how receptive they are to alternative pest management practices remains uncertain. Traditionally, agricultural policies and programs have focused largely on the economic self-interest of farmers, but these narrow approaches have proven insufficient to describe and predict conservation behaviors, and the study of environmental value orientations (EVOs) may better explain farmers' adoption of novel wildlife-friendly practices. The study of EVOs can help identify people as "mutualists", meaning those who value the environment for its own sake, and "utilitarians," meaning those who value the environment for the services it can provide. We surveyed 71 California winegrape growers in order to better understand how their underlying environmental values relate to the use of barn owl boxes and other sustainable practices. Overall, most winegrape growers had mutualist value orientations (64%). However, there was a disconnect between the use of barn owl boxes and EVOs, with most respondents (80%) reporting the use of owl boxes regardless of underlying values. This opens the door for future research to examine whether this is true of other wildlife-friendly farming practices.

Key words: barn owl boxes, California, environmental values, integrated pest management, sustainable farming, vineyards, winegrapes

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Addressing agricultural impacts to biodiversity demands that environmental scientists investigate sustainable farming practices (Godfray et al. 2010), including the use of integrated pest management (IPM). The principles of IPM involve creating management plans that

first rely on natural means, such as leveraging natural pest enemies, to control pests before turning to synthetic pesticides if necessary (Gray et al. 2009). The principles of IPM are gaining broad popularity across agriculture, and winegrape growing has been particularly successful at promoting IPM at an institutional level (Viers et al. 2013; Winkler et al. 2017).

California is the nation's most profitable agricultural state, and its most valuable crop is grapes, valued at $6.25 billion annually (CDFA 2018). Winegrape cultivation is a highly visible and economically important industry for the state (Dyer 2015), but winegrapes are particularly vulnerable to vertebrate pests, especially rodents (Gebhardt et al. 2011). Administration of toxic baits is a common conventional method employed to reduce rodent pest populations in agriculture (Tickes et al. 1982; Wood and Fee 2003). However, the use of rodenticides, including second-generation anticoagulant rodenticides (SGARs), poses serious risks to non-target wildlife, raising ethical concerns (Kross et al. 2019). Though SGARs are not permitted at field scales in winegrape vineyards, public concern is strong and winegrape growers have begun to pursue alternative approaches as part of IPM solutions in an effort to improve their public image and enhance economic and environmental sustainability (Gray et al. 2009). Among these alternatives is the use of nest boxes for barn owls (*Tyto furcata and T. alba*; Labuschagne et al. 2016), which has been practiced in commodity and forage crops such as maize (Ojwang and Oguge 2003) and alfalfa (Motro 2011), as well as luxury crops such as date palms (Meyrom et al. 2009) and winegrapes (Johnson et al. 2018). Although confirmation of whether barn owl nest boxes can meaningfully reduce rodent numbers in winegrape vineyards awaits experimentation, recent work showed they can help control rodent pests in Spain (Paz Luna et al. 2020). Empirical fieldwork in California showed they can remove large numbers of rodents from vineyard landscapes (Johnson and St. George 2020), and modeling suggests they may be able to help control gophers (Kross and Baldwin 2016) and other rodents (Meyrom et al. 2009; Hiroyasu et al. 2019) when their densities are not especially high.

There is little information about how winegrape growers have responded to the use of barn owl nest boxes, and how they may change their pest management practices to be more sustainable in the future (Kross et al. 2017). Wine consumers have demonstrated a willingness to pay more for products perceived as being environmentally friendly (Sellers-Rubio and Nicolau-Gonzalbez 2016; Schäufele and Hamm 2017) and profitability can influence producers' adoption of environmentally sustainable practices (Marshall et al. 2005). However, recent studies are finding more complex cognitive motivations for pro-environmental choices (Sulemana and James 2014; Thompson et al. 2015; Floress et al. 2017), with many researchers studying wildlife and environmental value orientations (Jacobs et al. 2014) that take into account psychosocial variables that acknowledge the complexity of human decision making. One such framework is the values-attitudes-behavior cognitive hierarchy (Cook and Ma 2014; Floress et al. 2017). In this approach, values are the most basic, fundamental beliefs, and norms by which individuals evaluate how desirable they find a given action or outcome (Fulton et al. 1996; Cook and Ma 2014). These values are the basis upon which attitudes are formed and attitudes then influence behavior. There is no perfect predictor of behavior, but there is evidence suggesting that understanding an individual's core values is critical for forecasting and potentially influencing their decision making (Ajzen and Fishbein 1977; Honig et al. 2015). This makes values research potentially powerful in efforts to increase sustainable practices.

In this study we assessed why California winegrape growers choose to engage in sustainable farming by parsing out the associations between environmental values and a

number of sustainable practices, including the use of barn owl boxes. Grounded in a wildlife value orientation (WVO) and cognitive hierarchy framework (Fulton et al. 1996), our study builds on the preliminary survey distributed by Wendt and Johnson (2017) in Napa Valley. Within the WVO literature, individuals are scored on their tendencies toward mutualism, placing intrinsic value on wildlife, and domination, prioritizing human needs over those of wildlife. They are then placed on a spectrum from mutualist, those who value wildlife for its own sake, to utilitarian, those who value wildlife as a service for human benefit (Fulton et al. 1996). We adapted this approach to more broadly apply to the natural environment.

We aimed to address three key areas for winegrape growers: environmental values, farming practices, and the association between the two. Specifically, we wanted to explore how winegrape growers' survey responses reflect mutualist or utilitarian values toward wildlife and the environment. We also sought to document which rodent pest control methods winegrape growers currently use and what sources of information they trust for pest control. Among respondents who use owl boxes for pest control, we examined how effective they feel nest boxes are at controlling rodents and how they see owls affecting their farms overall. Finally, we investigated what factors associate with winegrape growers use of more environmentally friendly practices and to what degree their behaviors align with utilitarian or mutualistic value orientations.

METHODS

Survey

Our survey was built around a modified version of the instrument developed by Fulton et al. (1996). For the values portion, respondents were presented with 20 statements and asked to evaluate the extent to which they agreed or disagreed with them based on a 7-point Likert scale from strongly disagree (1) to strongly agree (7).

These statements were intended to measure five wildlife and environmental belief dimensions: (1) wildlife rights, (2) wildlife use, (3) wildlife appreciation, (4) environmental protection concerns, and (5) willingness to use environmentally friendly farming techniques (see Table 1 for the list of questions and their alignment with these five dimensions). These five measures were then combined to measure two EVOs, (1) domination and (2) mutualism; see Table 1 for statement sorting. In this context, those with a domination value orientation are more likely to prioritize human well-being over the environment and welfare of wildlife, and they are more likely to find environmentally damaging behaviors to be acceptable if they serve a utilitarian purpose. Those with a mutualist value orientation are more likely to empathize with wildlife, find intrinsic value in the environment, and oppose environmentally damaging behaviors (Brodt et al. 2006; Teel and Manfredo 2010). The items in this instrument were adapted from similar surveys by Brodt et al. (2006), Fulton et al. (1996), Teel and Manfredo (2010), Thompson et al. (2015), and Whittaker et al. (2006). Most of the items for the belief dimensions involving environmental protection and farming practices were adapted from Brodt et al. (2006), modified to address agriculture-specific issues in place of the more residential or personal statements included in strictly wildlife-focused studies like Fulton et al. (1996) (see Estes 2019 for a complete breakdown of statement sources).

In addition to the questions aimed at environmental values, the survey included questions intended to document respondents' actions and perceptions relating to the use of barn owl boxes. The survey also included some basic demographic questions about respondents

Table 1. Confirmatory factor analysis (CFA) and reliability scores for items used to measure wildlife and environmental value orientations from a 2018 survey of California winegrape growers.

Wildlife/Environmental Value Orientations, Basic Belief Dimensions, and Scale Items[a]	Factor Loading[b]	F's alpha
Domination value orientation (2nd order factor)		0.88
Wildlife Rights belief dimension (1st order factor)	0.769	0.89
The needs of humans should take priority over fish and wildlife protection	0.882	
Although wildlife may have certain rights, most human needs are more important than the rights of wildlife	0.896	
The needs of people are always more important than any rights that wildlife may have	0.814	
The rights of people and the rights of wildlife are equally important[c]	0.714	
Wildlife Use belief dimension (1st order factor)	1.057[d]	0.71
Humans should manage fish and wildlife populations so that humans benefit	0.634	
It is acceptable for people to kill wildlife if they think it poses a threat to their life	0.683	
It is acceptable for people to kill wildlife if they think it poses a threat to their property	0.801	
We should strive for a world where there is an abundance of fish and wildlife for hunting and fishing	0.415	
Mutualism value orientation (2nd order factor)		0.87
Wildlife Appreciation belief dimension (1st order factor)	0.657	0.91
Wildlife is an important part of my community	0.914	
I'm interested in making the area around my farm attractive to wildlife	0.943	
Having wildlife around my farm is important to me	0.963	
Environmental Protection belief dimension (1st order factor)	1.012 [d]	0.76
I want to increase biodiversity on my farm even if it takes land out of production	0.732	
I strive to learn how to manage resources in cooperation with nature	0.519	
The environmental value of my farm is just as important as its agricultural value	0.641	
It is important to maintain biodiversity for future generations	0.834	
Farming Practices belief dimension (1st order factor)	0.89	0.75
I consider a decrease in pesticide use one way to improve living and working conditions on my farm	0.763	
I use whatever fertilizers and pesticides are necessary to get the job done[c]	0.635	
I am not willing to sacrifice farm profitability to conserve water or other resources[c]	0.454	
I cannot see using environmentally friendly management techniques if they sacrifice yield or crop quality[c]	0.631	

[a] Item response scale: 1 (strongly disagree) to 7 (strongly agree).
[b] Standardized factor loadings from CFA. Fit statistics: $\chi^2 = 223.41$ (df = 146; $p < 0.001$); CFI = 0.90; GFI = 0.77; RMSEA = 0.08; SRMR = 0.08.
[c] Item was reverse coded prior to analysis.
[d] Factor loadings greater than 1 likely reflect high multicollinearity (Jöreskog 1999).

(e.g. age, gender) and their property (e.g. acreage), and Likert scale questions about pest species, rodent control methods, farming techniques (organic, biodynamic, conventional, etc.), and levels of trust in different sources of pest control information (e.g. personal observation, research groups, peers). The full survey instrument can be found in Estes 2019.

Data Collection

All data collection was done in compliance with federal regulations on the use of human subjects and was approved by Humboldt State University's Institutional Review Board (IRB 16-231). Surveys were administered electronically via SurveyGizmo to California winegrape growers by contacting wine industry groups, starting with the Napa Valley Grapegrowers (NVG) and the statewide California Association of Winegrape Growers (CAWG), but this garnered relatively few responses. A more targeted effort was made to reach out to American Viticultural Area (AVA) associations and smaller sub-appellation groups, starting with those in Napa and expanding to all AVAs with an association for which contact information was available. In all, 35 groups were emailed, and the survey was distributed to the members of 14 groups, including the NVG (see Estes 2019 for a full list of participating groups). A small number of surveys were also obtained after emailing some vineyards directly, but the majority of responses came from members of smaller appellation and sub-appellation groups who were emailed a link to the survey. In total, 71 surveys were completed. Respondents must have finished at least the values questions to be considered complete as these questions formed to core of all subsequent analyses.

Data Analysis

This survey was conducted to obtain preliminary data from wine producers and inform future research. As such, an inductive approach was used, with numerous exploratory analyses to compare the attitudes of participating growers with existing wildlife and environmental values literature. There were 20 values statements in the survey, one of which, regarding wildlife suffering, was discarded for analysis due to poor fit with any models (see Estes 2019 for a complete list of items). Following the method pioneered in Fulton et al. (1996), the remaining 19 items were put through a two-stage confirmatory factor analysis (CFA) in AMOS (Arbuckle 2019) to test for internal consistency and goodness of fit. The first order analysis sorted statements into one of five factors corresponding to basic belief dimensions about (1) wildlife rights, (2) wildlife use, (3) wildlife appreciation, (4) environmental protection, and (5) farming techniques. These were then run through another CFA to separate these factors into two second-order factors corresponding to domination (factors 1 and 2) and mutualistic (factors 3-5) value orientations. These second order factor models had a chi-square of 223.41 ($df = 146$; $P < 0.001$). Several analyses were used to assess goodness of fit, CFI = 0.90, GFI = 0.77, RMSEA = 0.08, SRMR = 0.08, and while most did not reach suggested thresholds ($CFI \geq .95$, $GFI \geq 0.90$, RMSEA and $SRMS \leq 0.08$; Hooper et al. 2008; Kline 2011) likely due to the small sample size, the models were not discarded as this is an exploratory study. While useful, these fit indices are biased toward large sample sizes and there is evidence that they may not generalize well outside the narrow set of models from which they were developed (Barrett 2007; Kline 2011). Reliability analyses were also run in SPSS (IBM Corp 2017), and they indicated high inter-item consistency with Cronbach's alpha scores between 0.71 and 0.95 (see Table 1; Nunnally and Bernstein 1994).

Once values items were sorted by factor, an average for each first order factor belief dimension (e.g., wildlife appreciation) was calculated for each participant by averaging the corresponding Likert-scale responses. Then, the second order value orientations were calculated by taking the means of the corresponding belief dimension items. Based on these scores, respondents were then sorted into four groups by adapting the method used by Teel et al. (2005). Value orientation (second order factor) scores above 4.5 (out of 7) were considered "high" and less than or equal to 4.5 were considered "low." Participants who scored high on domination and low on mutualism were classified as "utilitarians," those who scored low on domination and high on mutualism were classified as "mutualists," those who scored high on both were classified as "pluralists," and those scoring low on both "distanced."

In subsequent analyses, the distanced category was excluded because only three respondents were classified into this group, and the utilitarian and pluralist groups were combined to facilitate substantive analyses because each group was small, 10 and 13 respondents respectively. This combined group then represented the 23 respondents that had a high domination score to compare to the mutualist group of 45 respondents with low domination scores. These two broad groups of respondents (low domination scores vs. high domination scores) were then used as independent variables in cross-tabulations for categorical response variables, and in independent samples *t*-tests for scaler response variables, to assess the differences in responses to other survey questions, such as percent non-crop habitat and use of pest control techniques. Binary responses, such as those who do and do not use owl boxes, were also used as independent variables to compare participants' domination and mutualism scores. See Estes 2019 for full survey instrument and variable breakdown.

RESULTS

There were 113 surveys submitted, of these 71 were complete and included in analyses. As the surveys were distributed by local and regional organizations to maintain their members' anonymity, a precise response rate cannot be calculated; however, it was likely less than 5% because the organizations' collective email distribution lists exceeded 2,000 recipients. Napa County was the most heavily represented, with 43.7% (n = 31) of respondents, the rest being spread across 10 other counties (Fig. 1). Of the respondents included in the analyses, 77.5% self-identified as male (n = 55) and 18.3% as female (n = 13); 64 respondents provided their age, of these the average age was 56 (SD = 12.54). A majority of respondents identified their role as owner/operator (87%, n = 62) with the remainder identifying as either part of a management company, a winemaker, or staff. The vineyards addressed in the survey were also mostly small, with 91.5% (n = 65) being 200 acres or less (Fig. 2).

In response to a question about reliability of various sources of information on pest management strategies on a scale of 1 (very unreliable) to 5 (very reliable), respondents found personal observation to be the most reliable (M = 4.04, SD = 0.98), followed by research groups (M = 3.90, SD = 0.97), and meetings or workshops (M = 3.64, SD = 0.99). Respondents found owl box experts (M = 2.79, SD = 0.86) and social media (M = 2.81, SD = 1.17) to be the least reliable, however, all other sources averaged above neutral (Fig. 3).

Value Orientations and Belief Dimensions

Over 80% of the 71 respondents scored high (>4.5) on the mutualism axis, whereas 32% scored high (>4.5) on the domination axis. Based on these scores, 14.1% of respondents

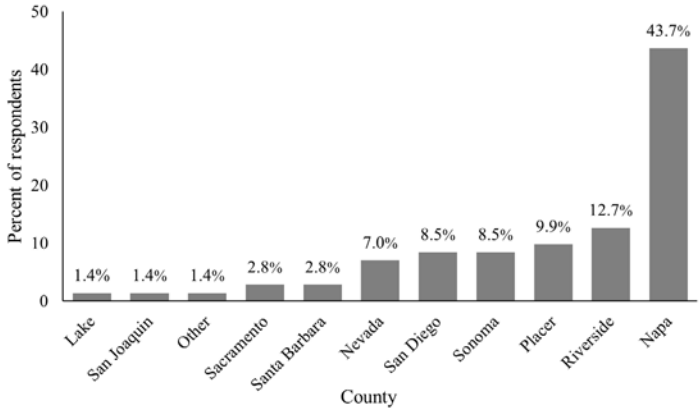

Figure 1. Percent of responses to a 2018 survey of California winegrape growers by county.

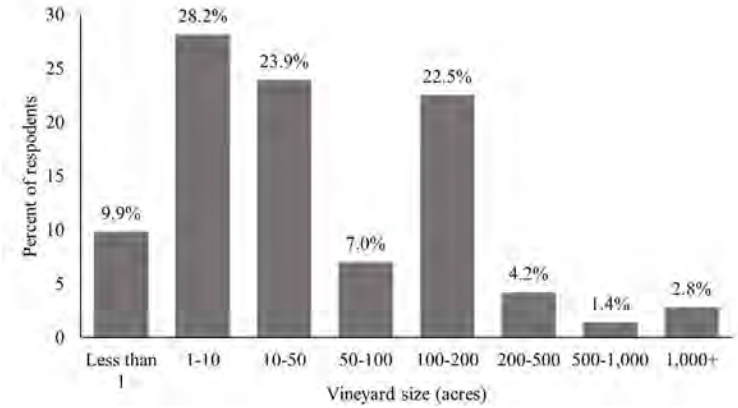

Figure 2. Frequency histogram of participant reported vineyard sizes from a 2018 survey of California winegrape growers.

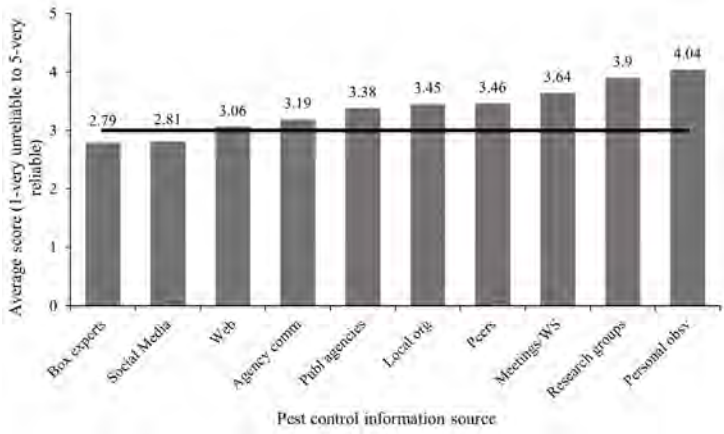

Figure 3. Average perceived reliability of pest control information sources from 1-very unreliable to 5-very reliable, from a 2018 survey of California winegrape growers. Horizontal line indicates an average score of 3-neutral.

were classified as utilitarian (high domination low mutualism), 18.3% as pluralists (high on both), 4.2% as distanced (low on both), and 63.4% as mutualists (high mutualism low domination; see Table 2). Additional descriptive statistics for utilitarians and pluralists can be found in Estes (2019, pg 114).

Table 2. Scoring of wildlife and environmental value orientation types based on value orientation scales and belief dimensions from a 2018 survey or California winegrape growers, adapted from Teel and Manfredo (2010).

Value orientation and belief dimension	Utilitarian (n = 10, 14.1%)		Pluralist (n = 13, 18.3%)		Mutualist (n = 45, 63.4%)		Distanced (n = 3, 4.2%)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Domination	5.54	0.67	5.60	0.65	3.48	0.76	4.13	0.13
Human priority	5.30	1.00	5.29	1.04	2.61	0.90	3.50	0.43
Wildlife use	5.78	0.49	5.90	0.55	4.35	1.00	4.75	0.50
Mutualism	3.80	1.16	5.47	0.69	5.93	0.64	4.39	0.10
Wildlife appreciation	4.16	0.24	5.85	0.81	6.21	0.92	5.00	0.00
Environmental protection concerns	4.58	0.67	5.27	0.87	5.96	0.74	4.17	0.29
Farming techniques	4.10	0.92	5.29	0.90	5.56	0.98	4.00	0.00

Several significant differences emerged between the mutualist and utilitarian/pluralist groups (Table 3). Mutualists tended to be younger and they reported a higher percentage of non-crop habitat on their farms. There was a comparatively higher proportion of mutualist females compared to males, however this difference was not statistically significant, possibly due to the overall male skew of respondents. There was also no statistically significant difference in farm size between mutualists and utilitarians/pluralists, though the former tended to have somewhat smaller farms (Table 3).

About half of respondents, 50.7% (n = 36), reported having at least one environmentally friendly certification, with Fish Friendly Farming being the most common at 29.6% (n = 21). However, this does not necessarily reflect how respondents were actually farming. For example, only 8.5% (n = 6) of respondents were certified organic by the United States Department of Agriculture (USDA) or California Department of Food and Agriculture (CDFA), but 26.8% (n = 19) reported using organic techniques. Similarly, only 4.2% (n = 3) reported being certified biodynamic, but 11.3% (n = 8) reported using biodynamic techniques. There were also 14 respondents (19.7%) who wrote in "sustainable" as the "other" option for techniques, while only 11.3% (n = 8) reported being certified sustainable by the California Sustainable Winegrowing Alliance (CSWA; Figs. 4 and 5).

Mutualists were more likely to have at least one certification and were more likely to use non-conventional techniques (organic, biodynamic, or sustainable) than utilitarian/pluralists (Table 3). The proportion of respondents attracting birds as a pest control technique and using owl boxes specifically were similar between mutualists and utilitarian/pluralists (Table 3). Utilitarians were somewhat more likely to use rodenticides than mutualists, but this difference was statistically marginal (Table 3).

Table 3. Comparison of wildlife and environmental value orientation types, participant demographics, and selected responses from a 2018 survey of California winegrape growers.

Variable	Utilitarian or Pluralist	Mutualist	χ^2 or F (df)[a]	P	ES[b]
Age ($\bar{\chi}$)	61.05	54.02	4.8 (1, 61)	0.03*	
Percent Non-crop Habitat ($\bar{\chi}$)	24.83	44.9	6.67 (1, 65)	0.01*	
Gender (%)			3.79 (2)	0.15	0.24
Female	8.7	24.4			
Male	91.3	71.1			
Farm Size in Acres (%)			12.9 3(7)	0.074	0.44
Less than 1	13	8.9			
1-10	47.8	20			
10-50	17.4	22.2			
50-100	8.7	6.7			
100-200	4.3	33.3			
200-500	4.3	4.4			
500-1,000	4.3	0			
1,000+	0	4.4			
At least one certification (%)			7.95 (1)	0.005*	0.34
Yes	26.1	62.2			
No	73.9	37.8			
Uses non-conventional techniques (%)			0.46 (1)	0.032*	0.26
Yes	34.8	62.2			
No	65.2	37.8			
Attract birds for pest management (%)			0.44 (1)	0.507	
Yes	82.6	75.6			
No	17.4	24.4			
Owl Box (%)			0.51 (1)	0.477	
Yes	87	80			
No	13	20			
Uses Rodenticides (%)			3.27 (1)	0.07	0.22
Yes	34.8	15.6			
No	65.2	84.4			

[a] Values from chi-squared or independent samples t-tests (two-tailed) with degrees of freedom.
[b] Effect sizes. Cramer's V was used for chi-squared analyses.

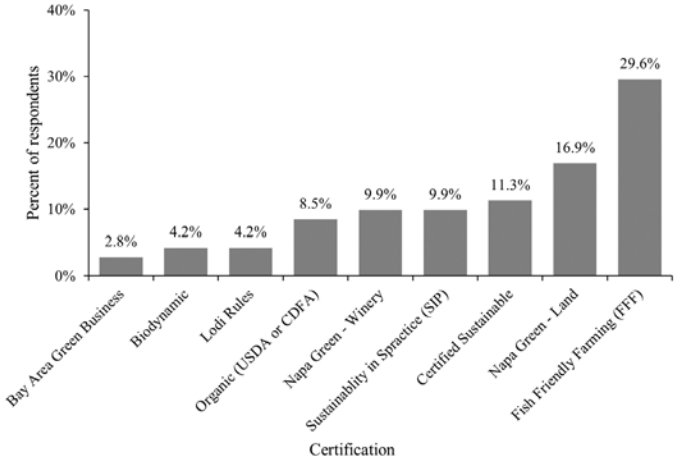

Figure 4. Percent of respondents with each environmental certification from a 2018 survey of California winegrape growers.

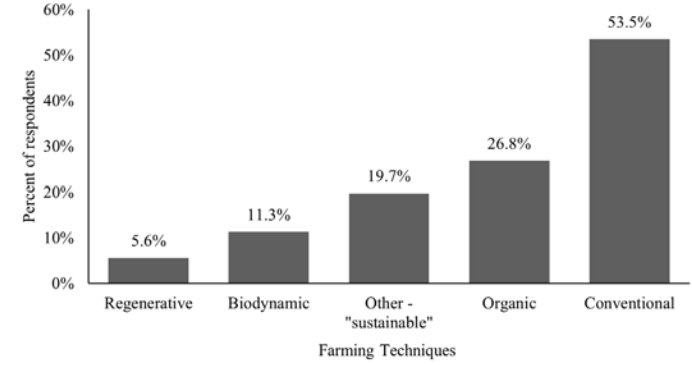

Figure 5. Percent of respondents to a 2018 survey of California winegrape growers who reported using different farming techniques. Other – "sustainable" refers to a write-in option.

Barn Owl Boxes

On a scale of 1 (not concerned) to 4 (very concerned), respondents were most concerned about rodent and insect pests, with an average response of 3.04 (SD = 0.96) and 3.0 (SD = 0.92) respectively. When asked about rodent pest control techniques the most respondents reported attracting birds, 77.5% (n = 55), followed by 52.1% (n = 37) who used rodent kill traps and 21.1% (n = 15) who used rodenticides. A majority of respondents also reported using barn owl boxes specifically (81.7%, n = 58), which limited capacity to statistically compare responses to other questions by those who did and did not use boxes. While the overall use of rodenticides was low, all but one of these respondents also reported using owl boxes. Of those using boxes, 13.5% (n = 8) also reported using some form of chemical rodenticide.

In response to the question on the effects of owl boxes on a scale of 1 (very harmful) to 5 (very beneficial), respondents on average rated them positively on five metrics. The effect on rodent pests scored the highest (M = 4.25, SD = 0.99), followed by tourism (M = 3.93, SD = 1.78), vine health (M = 3.47, SD = 0.66), grape yield (M = 3.32, SD = 0.60), and bird pests (M = 3.12, SD = 0.47).

Associations between respondents' value orientations (second order factor scores) and use of barn owl boxes were mixed. On average respondents who used owl boxes had a higher domination and lower mutualism score than those who did not, but the differences were not statistically significant (Fig. 6). Differences in average value orientation scores were statistically significant between those who did and did not use rodenticides, with those using rodenticides having higher domination and lower mutualism scores than those who did not (Fig. 6). Average value orientation scores also differed significantly based on certifications and sustainable technique use. Participants with at least one certification had a lower domination and higher mutualism score on average than those without; and participants who reported using sustainable techniques also had a lower domination and higher average mutualism score than those who did not (Fig. 6).

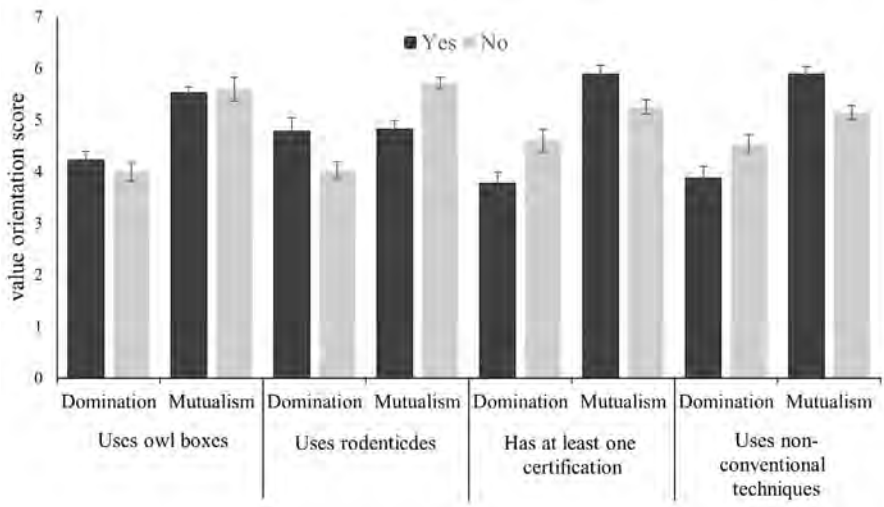

Figure 6. Average second-order factor value orientation scores (domination and mutualism) compared with standard error bars for the use of owl boxes, rodenticides, environmental certifications, and non-conventional techniques by California winegrape growers in 2018.

DISCUSSION

A better understanding of farmers' underlying values and how they relate to the use of environmentally friendly practices could inform outreach polices to help encourage their adoption (Brodt et al. 2006; Sulemana and James 2014). Analyses in this paper suggest that most winegrape growers surveyed tend more toward mutualist environmental values (high mutualist and low domination scores, 63% of respondents), than toward utilitarian values (high domination and low mutualism scores, 14% of respondents), or to pluralist values (both high utilitarian and mutualism scores, 18% of respondents). The proportion of respondents in this study that aligned with mutualist values is higher than most WVO research has found in the past. For example, in a 2005 survey of 7,388 respondents from 19 western states, only 35% were classified as mutualists, with 28% classified as utilitarians (called "traditionalists"), 21% as pluralists, and 15% as distanced (Manfredo et al. 2018). The higher proportion of mutualists among winegrape growers suggest they may be particularly receptive to considering adoption of environmentally friendly practices.

Grape-grower Use of Barn Owl Boxes and Other Non-conventional Techniques

Reported use of non-conventional farming techniques was high, with 53.5% (n = 38) of respondents indicating the use of at least one non-conventional farming technique. Direct comparisons with other data are not available, but it is reasonable to conclude that the winegrape growers in this study fall above the average for agricultural producers in general. For example, in this study 8.5% of respondents reported being USDA or CDFA certified organic, whereas less than 0.01% of farms nationally and 0.04% of farms in California were certified organic in 2016 (NASS 2017).

There is some ambiguity in these results, however, as the responses for various sustainable techniques did not align with certifications. For example, 23% of respondents (n = 16) indicated they used some kind of sustainable techniques but did not have any certifications. Conversely, 20% of respondents (n = 14) reported having at least one certification but did not indicate the use of any sustainable farming techniques. This particular discrepancy may be due to the fact that some certifications listed do not necessarily focus specifically on crop production (e.g. soil erosion, irrigation, habitat restoration, etc.). This is potentially important when considering how the perception of some environmentally friendly techniques may increasingly be somewhat divorced from their "sustainable" connotations.

It is striking that the most frequently reported strategy was attracting birds, at 77.5% (n = 55) and an overwhelming 82% (n = 58) of respondents reported using barn owl boxes specifically. The difference between these is due to six participants who indicated they used owl boxes but did not indicate that they attract birds to their property for rodent control.

Reported rodenticide use was low, at 21% (n = 15), but nearly all of these respondents also reported using barn owl boxes. This is potentially concerning as the primary strategy for deploying rodenticides is via bait stations, which allow rodents to disperse after consumption to potentially be predated by barn owls and other predators. In California, at the time of this survey, four common SGARs were classified as restricted materials that may only be applied by professionals with permits issued by a county commissioner (CDPR 2017), with a newly signed bill (AB 1788) introducing additional restrictions (Bloom et al. 2020).

There are also numerous other factors that are not taken into account by this survey; for example, grapegrowers may be using rodenticides only during non-breeding seasons when owl populations are much lower, in fields that are netted to keep out smaller bird pests, or they may be compensating for a decline in box occupancy, all of which would at least reduce the risk of exposure. Qualitative research is needed to clarify the issue and discern how aware these grapegrowers are of the potential hazards of overlapping rodenticides (Kross et al. 2019).

Associations between Barn Owl Box Use and Value Orientations

Examining the associations between respondents' value orientations (second order factors) suggests that while some behaviors did differ between mutualists and utilitarian/pluralists, the use of barn owl boxes was widespread among all participants. For example, there were strong differences in the proportion of mutualists and others in their reported use of non-conventional practices and some form of certification, but the use of barn owl boxes was over 80% regardless of respondents' value orientation (Fig. 6). This was a surprising result, and several lines of evidence suggest this result may reflect a normalization of the use barn owl boxes. Indeed, similar percentages of mutualists and utilitarian/pluralists used

barn owl boxes, and the domination and mutualism scores for those who did and did not use owl boxes were not significantly different.

The lack of association between barn owl box use and EVOs may relate, at least in part, to the values-attitudes-behavior cognitive hierarchy. This approach asserts that values are the most fundamental, least changeable part of an individuals' cognitive foundation; they are the basis for decision making and are embedded not only within the individual, but within families, groups, and society at large. As discussed by Manfredo et al. (2017), this makes it impractical to focus on trying to change values to reach conservation goals. While it is useful and important to understand how values influence behavior, changes in values happen slowly and are only minimally influenced by behavioral changes. Manfredo et al. (2017) suggest focusing instead higher up on the cognitive hierarchy; on attitudes, behaviors, and norms. This may be where owl boxes fit in.

There are likely mutualist winegrape growers who use owl boxes because they are in-line with their core values, but there must be other influences that can account for the high degree of adoption across the board. For example, Wendt and Johnson (2017) found that many grapegrowers believe the nest boxes help decrease pest problems, and evidence is accumulating to suggest that their use may reduce rodent numbers in fields (Kross and Baldwin 2016; Johnson and St. George 2020). Thus, the value of the pest control services provided by barn owls appears widely recognized among winegrape growers. Moreover, there is a low barrier to entry for this practice. Owl boxes are relatively cheap and easy to install with little oversight as there is no monitoring or recording that needs to be reported to regulators. Owl boxes also count toward many certifications that may allow growers to charge more for their products or attract more eco-minded consumers. Taken together, the increasing recognition of the practical value of owl boxes coupled with other benefits and a low barrier to entry may have encouraged their use well beyond those who may have initially adopted the practice out of principle and alignment with their core values.

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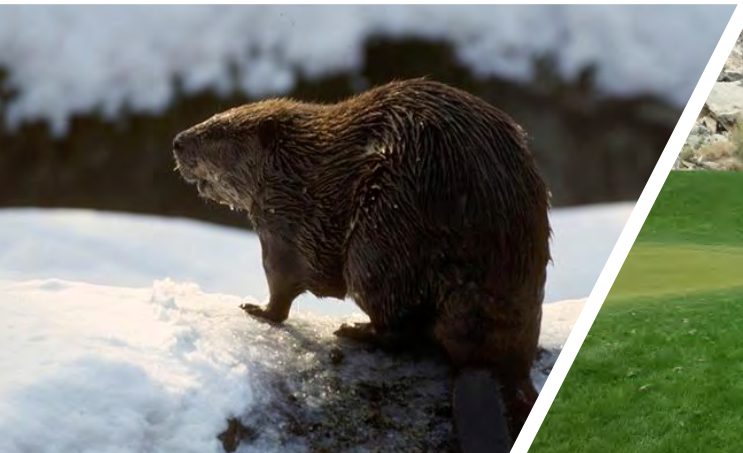
Human Dimensions of Wildlife Conservation



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1. San Joaquin kit fox (*Vulpes macrotis mutica*) with sarcoptic mange being treated at a wildlife rehabilitation center in Bakersfield, California. Photo Credit: California Department of Fish and Wildlife
2. Kayaks approaching sea otters (*Enhydra lutris*) to take photos in Morro Bay, California. Photo Credit: Gena Bentall, Sea Otter Savvy
3. Tilapia skin sewn by veterinarians to the burned paw of a black bear (*Ursus americanus*) injured in a wildfire. Photo Credit: California Department of Fish and Wildlife
4. Endangered Amargosa vole (*Microtus californicus scirpensis*) attached with a radio collar for Drought Stressor Monitoring research. Photo Credit: Risa Pesapane, University of California, Davis
5. North American beaver (*Castor canadensis*) in Winter in its natural habitat. Photo Credit: California Department of Fish and Wildlife OR
6. Desert bighorn sheep (*Ovis canadensis nelsoni*) seeking greener pastures on a golf course in California. Photo Credit: California Department of Fish and Wildlife

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FULL RESEARCH PAPER

Coyote Management Plans and Wildlife Watch: implications for community coaching approach to public outreach in southern California

ALEXANDER HEEREN[1]*, HELEN BOWMAN[1], VICTORIA MONROE[1], DAVID DODGE[2], AND KENT SMIRL[2]

[1] *California Department of Fish and Wildlife, Wildlife Investigations Laboratory, 1701 Nimbus Rd, Rancho Cordova, CA 95670, USA*

[2] *California Department of Fish and Wildlife, Natural Resource Volunteer Program, 4665 Lampson Ave, Los Alamitos, CA 90720, USA*

**Corresponding Author: alexander.heeren@wildlife.ca.gov*

The majority of residents in southern California live in urban areas. Therefore, working with cities to promote tolerance and coexistence with urban wildlife is crucial to the conservation and management of native species. Human conflicts with coyotes (*Canis latrans*) illustrate the importance of incorporating the social sciences, particularly knowledge of human behavior, communication, and education, in a coyote management strategy. Here, we review 199 cities across southern California to determine which localities have a coyote management website or a coyote management plan. We also included cities that have collaborated with the California Department of Fish and Wildlife in developing a "Wildlife Watch" program model. Wildlife Watch (based on the Neighborhood Watch national crime prevention program) uses conservation-oriented principles to empower local communities, agencies, and residents to remove wildlife attractants and to exclude or deter coyotes from neighborhoods. We examine how cities with coyote management websites and programs differ from cities without, based on U.S. census demographics. Using data from coyote conflict and sighting tools (Coyote Cacher, iNaturalist, and CDFW's Wildlife Incident Reporting System) we compare coyote reports across cities with different management plans and websites. Finally, based on demographics from the US Census, we examine ways Wildlife Watch, or related programs, can be expanded and improved. An adaptive community-based program, like Wildlife Watch, offers a valuable toolkit to managers for navigating the diverse array of human perceptions, values, and attitudes regarding urban species and human-wildlife conflicts.

Key words: *Canis latrans*, co-existence, coyote, education, human-wildlife conflict, socio-economic studies

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Human-wildlife interactions leading to urban wildlife conflict, particularly involving coyotes (*Canis latrans*) is a major wildlife conservation and management issue in southern

California (Baker and Timm 1998; Baker 2007). Human-wildlife conflict has a large social component (Madden and McQuinn 2020; Manfredo 2008). While the state manages wildlife through the California Department of Fish and Wildlife (CDFW), local governments and community leaders also have an important role to play in managing wildlife within their jurisdictions. As the majority of southern Californians oppose lethal control of coyotes [less than 30% of Los Angeles, Orange, and San Diego residents are estimated to support lethal control of coyotes that injure or kill pets or domestic animals (Manfredo et al. 2018)] nonlethal methods to achieve co-existence and tolerance of wildlife is the primary goal for urban coyote management. In pursuit of coexistence, community outreach, education, and communication about how to avoid conflict are an important component of any coyote management plan (Baker 2007; Sponarski et al. 2016). Currently, CDFW works with local governments, non-governmental organizations (NGOs) and other partner agencies in developing community outreach and communication about wildlife.

An example of one such outreach program in California is Wildlife Watch (CDFW 2020). Wildlife Watch is a program model operated by CDFW that partners with cities, local communities, and neighborhoods. Wildlife Watch attempts to replicate the success of the crime prevention program, Neighborhood Watch (Bennett et al. 2008; National Neighborhood Watch 2020), by engaging and empowering residents to monitor and report coyote activity in their neighborhoods, remove food and attractants from their property, and safely deter habituated coyotes using hazing techniques. Using the concepts of Servant Leadership (Greenleaf 1977), Wildlife Watch volunteers and staff, known as Conservation Coaches, attend and present at townhall and community meetings, coordinate and conduct partner agency and community trainings. They serve as a conduit that conveys wildlife conservation management science and information from CDFW to local city and community leaders. One of the primary goals of Wildlife Watch Conservation Coaches is working with cities to develop an integrated wildlife management plan to address resident concerns about wildlife in a safe, sustainable, and socially acceptable manner. Wildlife management plans may be species specific, such as a regional, county or city coyote management plan, or more species inclusive and comprehensive in scope.

Cities face many other challenges in addition to managing urban wildlife. Understandably, many cities are unable to devote time and resources to developing a coyote management website, a coyote management plan, or participating in Wildlife Watch. Reviewing which cities currently have coyote management websites or plans can help identify which areas require additional help in developing a coyote management plan or outreach efforts.

METHODS

This review builds upon a previously developed data set (Heeren et al. 2020a). A total of 199 cities from six counties (Ventura, Los Angeles, Orange, Riverside, San Bernardino, and San Diego) were included in the review (Table 1). The U.S. Census (USCB 2020) was used to establish a list of incorporated cities and villages in southern California. Data from the US Census 2019 American Community Survey provided estimates for city demographics (population size, race and ethnicity, language fluency, and median income). The website for each city was examined for any links or references to coyote or wildlife issues. Using this approach, we identified the cities that had a coyote management website, or a coyote management plan, available to residents online. A list of cities that have collaborated with CDFW on a Wildlife Watch program was obtained from CDFW records.

Table 1. Cities reviewed by county.

County	Total Cities Reviewed	Cities with Website Only	Cities with Coyote Management Plans (Non-Wildlife Watch Program)	Cities with Wildlife Watch Program
Los Angeles	87	32 (37%)	17 (20%)	9 (10%)
Orange	34	14 (41%)	8 (24%)	7 (21%)
Riverside	28	10 (36%)	0	0
San Bernardino	23	5 (22%)	1 (4%)	0
San Diego	18	2 (11%)	0	0
Ventura	9	3 (33%)	0	0

Cities were considered to have a website about coyote management if they had any webpages, or information referencing, coyotes, on their city website. This information could be educational, or information on how to report coyote incidents. Cities were considered to have a management plan if they had a link on their website to a larger document (such as a PDF) about how the city manages coyotes. A coyote management plan is a requirement for Wildlife Watch, so all cities with a Wildlife Watch program had a website and management plan.

Reports about coyote activity were taken from a previous study of a state-wide analysis of the Coyote Cacher online reporting tool, the iNaturalist reporting tool, and CDFW's Wildlife Incident Reporting tool (Heeren et al. 2020b). For a more in-depth discussion of these tools, and how they differ, please see Heeren et al. 2020b. All three of these tools are publicly available and residents can use them to report coyote sightings as well as any human-coyote interactions.

The review, US Census data, and coyote reporting data were compared using Microsoft Excel Version 2010, ArcGIS.

RESULTS

Approximately one-third (33.2%) of cities had a coyote management website, but no formal coyote management plan or document available to the public. Thirteen percent had a website with a coyote management plan. Eight percent of cities had a Wildlife Watch program. Of the 16 cities that had a Wildlife Watch program, 9 were in Los Angeles County and 7 were in Orange County.

Select demographics for the cities were compared using data from the US Census' 2019 American Community Survey (Table 2). These demographics were total population size, percentage of residents who identified their race or ethnicity as white or Caucasian, Asian, or Hispanic. Census estimates for the percentage of residents (5 years of age or older) that had difficulty speaking English were also included as well as the median household income. Language fluency and median income were only available for 133 cities in the review.

There was quite a range in the population size for the cities, regardless of whether the city had a coyote management website or plan (Table 2). Based on means and 95% confidence intervals, cities with a website or plan had a higher percentage of residents identifying their race or ethnicity as Asian compared to cities without a website, plan, or Wildlife Watch program. Cities with a coyote management website or Wildlife Watch program had

Table 2. Mean (95% Confidence Interval) demographics of cities with coyote management website, plan, or program

	Population n (1,000)	Identify Race or Ethnicity as White or Caucasian	Identify Race or Ethnicity as Asian	Identify Race or Ethnic-ity as Hispanic	Language	Median Income ($1,000)
No coyote management website or plan found	72 (42-103)	69.4 (65.9-72.9)	10.1 (8-12.2)	48.3 (43-53.6)	20.4 (18.2-22.6)	67 (62-71)
Website only	135 (19-252)	65.1 (60.3-69.9)	18.9 (14.9-22.9)	34.5 (29.3-39.7)	18.2 (15.7-20.7)	84 (79-89)
Coyote Management Plan (Non-Wildlife Watch)	81 (42-121)	57.5 (49.3-65.7)	23.3 (16.2-30.4)	39.4 (30-48.8)	26.5 (22-31)	73 (65-81)
Wildlife Watch Program	109 (62-156)	64.2 (56.7-71.7)	23.4 (17.2-29.6)	28.5 (18-39)	15.6 (12.1-19.1)	94 (84-104)

a lower percentage of residents identifying their race or ethnicity as Hispanic than those with a Wildlife Watch program. Cities with a Wildlife Watch program had lower estimates of residents who had difficulty speaking English, and higher median incomes than cities without a Wildlife Watch program.

For reporting coyote activity, cities with a Wildlife Watch program, or coyote management plan, tended to have more reports (per 1,000 residents) than those without a Wildlife Watch program or without a coyote management plan (Table 3). However, due to the variance in reporting activity, the 95% confidence intervals are overlapping.

DISCUSSION

An adaptive community-based program, like Wildlife Watch, offers a valuable toolkit for managers to support safer human-wildlife interactions, increase awareness, and encourage coexistence and tolerance for urban wildlife, particularly coyotes. While a third of cities in southern California have some sort of website about coyote management, only a fifth have some sort of coyote management plan or Cities without a Wildlife Watch program tend to have a higher percentage of residents who identify their race or ethnicity as Asian and a

Table 3. Mean (95% Confidence Intervals) coyote reports per 1,000 residents of cities with coyote management website, plan, or program

	Coyote Cacher	iNaturalist	CDFW WIR
No coyote management website or plan found	0.33 (0.08-0.58)	0.19 (0-0.38)	0.03 (0.02-0.04)
Website only	0.85 (0-1.79)	0.29 (0-0.76)	0.04 (0.03-0.05)
Coyote Management Plan (Non-Wildlife Watch)	0.97 (0.41-1.53)	0.06 (0.02-0.1)	0.06 (0.03-0.09)
Wildlife Watch Program	1.32 (0.55-2.09)	0.1 (0.04-0.16)	0.05 (0.02-0.08)

lower percentage that identify has Hispanic than cities without a website or coyote management plan. Cities with a coyote management plan, or a Wildlife Watch program, also tend to have higher median incomes than cities without a coyote management website or plan.

This suggests that one way to improve Wildlife Watch, or related programs, is to figure out ways that cities can pool their resources to develop a program. Cities with a lower median income, and presumably a lower tax base, likely will have difficulties in devoting resources to wildlife management. By pooling resources, multiple cities in an area could develop a joint management plan or program. Such a collaborative management plan is currently underway with several of south Californian council of governments (COGs). Likewise, cities with limited financial resources may require assistance from CDFW or non-governmental agencies, in applying for grants and other financial opportunities to develop a management plan or program.

While there did not seem to be a significant difference in language fluency between the cities with a plan or program to those without a plan or program, developing outreach materials in different languages could still promote a greater feeling of inclusivity with different communities. For example, most of the websites, plans, and Wildlife Watch program materials are in English. However, having Spanish-Language versions could help build connections to Hispanic communities.

It is difficult to make conclusions based on the results of the coyote reporting tools due to the great variance in reporting behavior (see Heeren et al. 2020b for more discussion). However, it seems that cities with a management plan or Wildlife Watch program do have higher rates of reporting. This makes sense as monitoring and reporting coyote behavior is a major component of these plans and programs. Residents are encouraged to keep an eye out for coyotes and to report interactions in the interest of pinpointing specific neighborhoods or properties that may have a problem with coyote attractants. However, given the nature of this data, it is not possible to determine how much of an increase in reporting is due to having a coyote management plan or Wildlife Watch program. Cities that developed such plans and programs did so because they had a dedicated set of residents invested in coyote issues, and likely had higher rates of reporting coyotes prior to the development of the plans or programs.

Wildlife Watch is still in its infancy, and therefore, this review is largely a pilot study to establish a baseline set of data for future research. In light of this, the review has several important limitations. First of all, the review only examined city websites. Other organizations, such as counties, COGs, school districts, homeowner associations, wildlife rehabilitation centers, and NGOs are also important stakeholders in managing urban wildlife. Working with non-city organizations to build coexistence and tolerance for urban wildlife is crucial.

Secondly, the demographics used in this review are at the city level and not necessarily representative of those residents who participated in developing coyote management websites, plans, or Wildlife Watch. Regardless of the city-level demographics, it is important to make ensure inclusivity and transparency in developing any wildlife management plan or program. This will ensure that the decision-making process reflects a diversity of views as well as making the materials accessible to a diverse audience.

Despite being in its early stages, we believe Wildlife Watch serves as a valuable resource that cities can draw upon when managing conflict with coyotes. Through the principles of Conservation Coaching and Servant Leadership, Wildlife Watch engages and empowers communities to take responsibility for preventing human-wildlife conflict. To conclude with

the words of a Wildlife Watch Conservation Coach in Orange County's City of Irvine: "My neighbors and I now feel empowered rather than helpless and have clear direction on how to cohesively move forward in a positive direction."

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ESSAY

The Respect Wildlife Campaign: A collaborative effort to reduce human disturbance to California's coastal wildlife

NICOLE B. TURNER[1], GENA B. BENTALL[2], COLLEEN YOUNG[3]*, ANDREW B. JOHNSON[4], WILLIAM G. STANDLEY[5]

[1] *National Park Service, 1201 Oakridge Dr., Fort Collins, CO 80525, USA*

[2] *Sea Otter Savvy, 1961 Main St. 199, Watsonville, CA 95076, USA*

[3] *California Department of Fish and Wildlife, Marine Wildlife Veterinary Care and Research Center, 151 McAllister Way, Santa Cruz, CA 95060, USA*

[4] *Defenders of Wildlife, 762 Laurel Avenue, Pacific Grove, CA 93950, USA*

[5] *Bureau of Land Management, California Coastal National Monument, 940 2nd Ave, Marina, CA 93933, USA*

**Corresponding Author: colleen.young@wildlife.ca.gov*

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A form of nature-based tourism known as *ecotourism* is an immense and burgeoning industry (Bowker et al. 2012; Balmford et al. 2015; Murray et al. 2019). For a time, the boon of ecotourism seemed an irreproachable alternative to the extractive exploitation of wildlife, and many communities derived benefits by preserving living, thriving natural areas and encouraging tourism in a non-consumptive manner (Duffus and Dearden 1990; Gössling 1999; Stronza et al. 2019). However, as more people have sought experiences in nature and encounters with wildlife, the risks of overcrowding sensitive habitats and disturbing the vital behavior patterns of the species living in those habitats have mushroomed. Without intervention, upsurges in outdoor recreation (e.g., Bowker et al. 2012; Mitrovich et al. 2020) and visitation to California's natural areas (National Park Service 2020; Pendleton and Kildow 2006) will negatively impact wildlife through human disturbance (Larson et al. 2016; Lucas 2020; Steven et al. 2011). Can communities in California preserve the benefits of ecotourism and other human recreational activities while mitigating some of their more adverse consequences on coastal wildlife?

Visitors to California's coastal areas seek opportunities to view and photograph marine wildlife specifically, or they may incidentally encounter marine wildlife while partaking in other activities (e.g., hiking, kayaking, boating, stand-up paddleboarding, scuba diving, fishing, tide-pooling, sightseeing, exercising, picnicking). For locals and visitors alike, seeing or photographing a bird taking flight or catching the gaze of a seal can be an exhilarating

experience and a treasured connection with nature. The skyrocketing popularity of posting wildlife encounters (e.g., wildlife selfies) on social media can drive visitors to engage in risky close approaches to obtain the perfect photograph (Ward-Paige 2016; Cherry et al. 2018; Pagel et al. 2020). But the human experience—the risks and rewards of wildlife encounters—does not always end well for the animals.

Visible changes in an animal's behavior can signal the disruption caused by close approaches by humans (Fig. 1), but some species can experience an elevated heart rate (stress response) without overt behavioral change (MacArthur et al. 1982; Coetzee and Chown 2016). Frequent and chronic disruption leads to reduced fitness, disrupts vital and sensitive activities—feeding, breeding, nursing, resting, migrating—and contributes to negative consequences (e.g., energetic stress, separation of mothers and young, interference in parental care, habituation, site abandonment), all of which can impact survival and population viability (Spaul and Heath 2016; Monti et al. 2018; Perona et al. 2019; Doherty et al. 2021). Whether intentional or inadvertent, human disturbance alters an animal's normal behavior, carries a physiological cost, and can produce cascading, ecosystem-wide consequences (Klein et al. 1995; Heil et al. 2007; Gaynor et al. 2018; Suraci et al. 2019; Doherty et al. 2021).

The COVID-19 pandemic has added to the complexity and urgency of the wildlife-disturbance issue by triggering unprecedented and unexpected shifts in outdoor recreation activities, especially in coastal areas. The outdoor gear industry saw a 56% sales jump in paddlesport equipment and a 31% increase in camping equipment in June 2020 over the same period in 2019 (NPD Group 2020). Highlighted on social media as a COVID-safe activity, tide pooling in locations like Pillar Point near San Francisco exploded, with hundreds of visitors crowding these areas during low tides (Marshall-Chalmers 2021). Despite limitations on daily entries, reduced services, and timed reservations, visitation boomed at some national parks through summer 2020 (Rott 2020). This upsurge in outdoor recreation, fueled in part by people with little or no experience in nature and lacking awareness of Leave No Trace principles (Marion and Reid 2001), likely increased the occurrences of wildlife disturbance and habitat degradation in 2020. COVID-19 restrictions further exacerbated the problem of wildlife disturbance by curtailing formal interpretive programs at state and federal parks and virtually eliminated in-person delivery of information to recreationists about appropriate behavior around wildlife.

Figure 1. Examples of visible changes to sea otter behavior due to human disturbance. (A-D) A time series of 4 images captured through a high-powered spotting scope showing a group of sea otters being disturbed by an approaching kayaker. (A), the group is resting, (B) the otters are alert, (C) the animals are agitated and one dove, and (D) the entire group dove. (E) A large raft of sea otters fleeing from a pursuing kayak.

Human disturbance of wildlife is a global issue that affects innumerable species (Larson et al. 2016). A growing body of research into the consequences of human-caused disturbance has revealed that some species or taxonomic groups are more vulnerable to disturbance and are more frequently disturbed. Additionally, species that garner more public interest can generate funding to study wildlife-disturbance issues. Marine mammals comprise charismatic species that have suffered well-documented incidences and costs of anthropogenic disturbance. Phocids, or true seals, are among the best-studied marine mammals with respect to human disturbance. Documented impacts range from visually apparent reactions like behavioral changes (e.g., van Polanen Petel et al. 2008) and site abandonment (e.g., Kenyon 1972) to less obvious internal physiological changes, such as increased heart rate (e.g., Karpovich et al. 2015). A study of harbor seals (*Phoca vitulina*) at Bolinas Lagoon in Marin County, California, found that humans disturbed seals on 71% of the days that researchers monitored them and that 72% of disturbances caused seals to disperse, resulting in short-term (28 ± 20.8 min) site abandonment (Allen et al. 1984). A study spanning three decades by Becker et al. (2011) at nearby Drakes Estero, also in Marin County, found that disturbance caused by mariculture activities resulted in long-term spatial displacement of breeding and pupping harbor seals.

Scientists have documented harmful effects from human disturbance in a myriad of other marine mammal species. For example, changes in activity budgets and increased energetic costs to killer whales (*Orcinus orca*) in response to boat traffic (Williams et al. 2006), behavioral changes of gray whales (*Eschrichtius robustus*) in response to anthropogenic noise (Moore and Clarke 2002), reduced foraging activity of bottlenose dolphins (*Tursiops truncatus*) in response to vessel presence (Pirotta et al. 2015), and increased behavioral responses and associated energetic costs of southern sea otters (*Enhydra lutris nereis*) in response to various anthropogenic stimuli (Barrett 2019). Significant effort has gone into mitigating disturbance to marine mammals, including federal legislation such as the Marine Mammal Protection Act (1972), regional and local restrictions such as seasonal and geographic closures and distance regulations (e.g., Young et al. 2014), and outreach programs such as Team OCEAN (Gunvalson 2011), with variable, but generally insufficient, effectiveness.

The public is often less aware of the effects repeated disturbances have on seabirds. Disturbance to seabirds is harmful and is particularly pronounced during the nesting season (e.g., Beale and Monaghan 2004). Human disturbance of nesting activity can lead to nest abandonment, dislodging of eggs and chicks from nest sites, predators feeding on eggs and chicks, exposure of eggs and chicks to heat or cold, and drowning of chicks when forced to fledge early. Specifically, human disturbance has been shown to reduce reproductive success in surface-nesting seabirds such as brown pelicans (*Pelecanus occidentalis*; Anderson and Keith 1980; Anderson 1988) and common murres (*Uria aalge*; Rojek et al. 2007); burrow-nesters such as Cassin's auklets (*Ptychoramphus aleuticus*; Albores-Barajas and Soldatini 2011); rocky-shoreline-nesting birds such as European oystercatchers (*Haematopus ostralegus*; Verhulst et al. 2001); and beach-nesting birds such as western snowy plovers (*Charadrius nivosus nivosus*; Lafferty 2001; Ruhlen at al. 2003).

Some studies have even documented impacts of human disturbance on invertebrate communities within rocky intertidal habitats in California (e.g., Lucas and Smith 2016); wildlife that often are not considered by the public as they flock to shorelines and parks in droves for recreational pursuits. Some invertebrates may shift their distribution within the intertidal habitat (e.g., Lucrezi et al. 2009) and other populations may be artificially elevated,

fostered by visitor food scraps (e.g., Steiner and Leatherman 1981; Schlacher et al. 2011), which in turn may increase intraguild predation. Recreational harvesting of mussels and other habitat-forming species could weaken the intertidal habitat (Marshall-Chalmers 2021).

Although several laws prohibit the disturbance of wildlife, such as the Marine Mammal Protection Act, the Endangered Species Act, and the Migratory Bird Treaty Act, enforcement personnel cannot monitor the millions of users spread along the California coastline. The legal definitions of what constitutes wildlife disturbance are vague, open to interpretation, and difficult for the general public to understand. As a result, resource managers have primarily defaulted to requiring or recommending minimum distance guidelines for avoiding wildlife disturbance. Though these distance guidelines are well-intentioned, research indicates that compliance can be low (e.g., Johnson and Acevedo-Gutiérrez 2007; Acevedo-Gutiérrez et al. 2011), the recommendations may not be adequate for particular species or taxa (e.g., Beale and Monaghan 2004; Young et al. 2014), and enforcement can be difficult or impossible. Additionally, visitors' perceptions of acceptable approach distances for wildlife rarely match the established distance guidelines or regulations (e.g., Taylor and Knight 2003). In most cases, individuals intend no harm and do not believe that their actions will alter wildlife behavior and cause undesirable effects (e.g., Slater et al. 2019); however, once a disturbance occurs, many recreationists will attempt to shift blame for wildlife disturbance to others rather than accepting personal responsibility for their conduct (e.g., Taylor and Knight 2003).

To improve compliance with guidelines, agencies and groups have employed signs as a tool for obtaining compliance with wildlife protection laws and guidelines and for reducing wildlife disturbance; however, little evidence exists that signs can produce immediate or lasting behavior change (e.g., Acevedo-Gutiérrez et al. 2011). Governmental and nongovernmental entities (e.g., National Oceanic and Atmospheric Administration, Sea Otter Savvy) have also implemented localized and taxa-specific measures to minimize disturbance to coastal wildlife in California. Examples of these initiatives and taglines include Whale SENSE, No Selfies with Seals, SeaLife Stewards, and Respect the Nap. While some of these actions have yielded reductions in disturbance (Gunvalson 2011; Allbrook and Quinn 2020), messaging within the various programs about approach distances and avoidance measures has often conflicted (Fig. 2), and most actions have not halted the increasing trajectory of disturbance or created lasting behavioral change in coastal visitors. In recognition of these issues, wildlife-disturbance experts along the California coast began coordinating their efforts to reduce wildlife disturbance by attending the first California Coastal Wildlife Disturbance Symposium (CCWDS) in 2015. The CCWDS brought together staff from government, NGOs, and local businesses to discuss the relative effectiveness of diverse efforts to mitigate human-caused disturbance to coastal wildlife. At that first CCWDS, the idea of developing a statewide campaign to address disturbance to marine wildlife in California emerged during a small breakout session. The group identified that while localized efforts to curtail coastal wildlife disturbance had occurred, no unified statewide effort existed in California to tackle the problem. Subsequently, the group recruited a diverse coalition of experts to advise on the development of a formal initiative, the Respect Wildlife Campaign (RWC), that would generate consistent science-based messaging across multiple communications platforms and define, establish, and instill a norm of responsible behavior among people in the presence of marine wildlife.

Over the past five years, an RWC working group has met regularly to work toward the development and implementation of the RWC. The RWC approach is unique because the

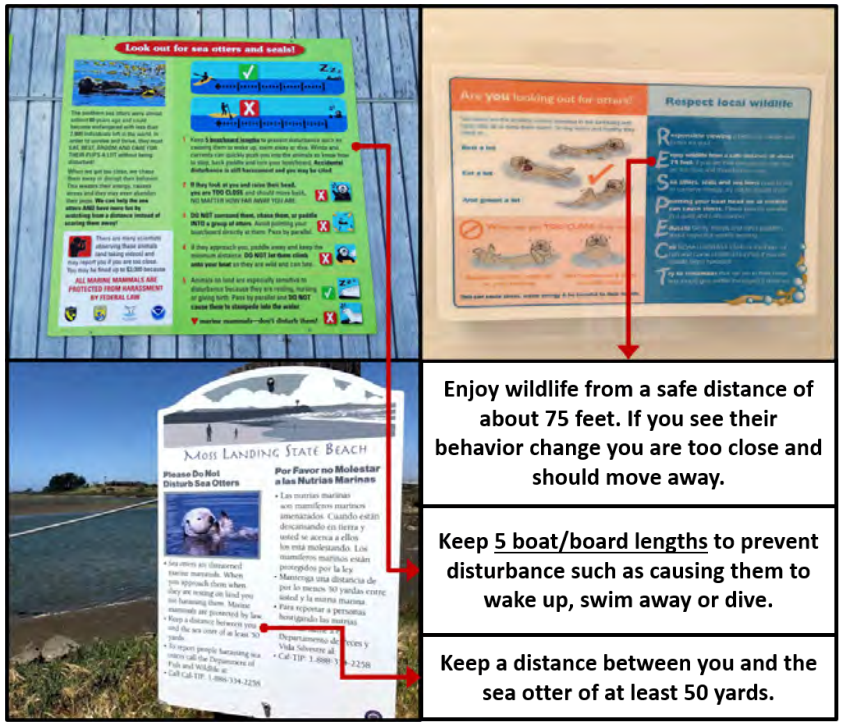

Figure 2. Examples of signs posted in Moss Landing, California, that provide conflicting guidance about the appropriate distance for paddlers to avoid disturbing sea otters.

core collaborating group includes meshes information from biologists, interpreters, resource managers, and social scientists from governmental agencies and non-governmental organizations with extensive input from local marine-recreation business operators, communication and marketing experts, and other stakeholders (see Table 1). The RWC has maintained its connection to the CCWDS, which has become a valued forum for organizers and attendees to share ideas, celebrate innovation, and learn from each other's successes and failures. During the COVID-19 pandemic, the CCWDS transitioned to a virtual platform in 2020 and broadened its reach to more than 130 attendees from 30 agencies, organizations, and other entities in California and other states. This experience brought home the power of virtual platforms for reaching new audiences and creating new partnerships. Although social media can exacerbate wildlife disturbance by showing people engaged in improper behavior around wildlife, the RWC sees opportunities to alleviate human impacts using those same platforms.

A fundamental lesson from the past five years of RWC collaboration is that changing human behavior is a complex endeavor. While it is clear that wildlife benefits the most when groups work in partnership to create unified, consistent messaging, the challenge of reaching diverse audiences with messages that will inspire and endure persists. The RWC aspires to plant seeds of awareness that will touch upon people's core beliefs or educate in such a way that respectful wildlife engagement becomes a part of those core beliefs. The RWC messaging will use the concept of *conflict transformation* to deconstruct embedded beliefs and behavior toward wildlife and realize constructive change (Lederach and Maiese

Table 1. Core collaborators in the California statewide Respect Wildlife Campaign.

Core Collaborator	Entity Type
Audubon California	nonprofit organization
Bureau of Land Management	federal agency
California Department of Fish and Wildlife	state agency
MPA Collaborative Network	sponsored organization
California State Parks	state agency
Defenders of Wildlife	nonprofit organization
Monterey Bay Kayaks	for profit
Office of National Marine Sanctuaries	federal agency
National Park Service	federal agency
Oceans Unmanned	federal agency
Save the Whales	nonprofit organization
Sea Otter Savvy	nonprofit organization
U.S. Fish and Wildlife Service	nonprofit organization

2003; Zimmermann et al. 2020). A conflict transformation approach will reframe the conflict (i.e., wildlife disturbance) from a problem to an opportunity, a shift in perspective that will build relationships and engender improved behavior (i.e., respect) toward wildlife. All RWC messaging will seek to transform wildlife viewers who inadvertently or intentionally harm wildlife into advocates for responsible wildlife viewing (Ardoin et al. 2015).

To evaluate the RWC's effectiveness and contribute to the body of knowledge on how to change human behavior to protect coastal wildlife, social scientists within the RWC collaborative group will employ an arsenal of survey instruments to collect data over five years on a range of campaign actions. Social media metrics, survey analyses, interviews, field monitoring, and other tools will document the efficacy of interpretive information, education and outreach initiatives, and social media ads in an effort to identify how human behavior changes with respect to coastal wildlife disturbance. In turn, clarifying people's perceptions, values, and expectations regarding marine and coastal wildlife, ecosystems, and habitats will help inform and guide the ongoing refinement of outreach and communication strategies. From a management perspective, the RWC will encourage improved public compliance with wildlife protection laws, regulations, and guidelines. To solidify and reinforce its messaging, the RWC will publicize information about measurable decreases in the incidence of wildlife disturbance and any resulting short- or long-term positive individual and population-level effects for coastal species.

With visitation to natural areas increasing and novices attempting new outdoor recreation activities, the need for clear, consistent messaging to protect wildlife and fragile ecosystems across parks, beaches, and open spaces in California will only intensify (Ardoin et al. 2015). Whether or not people engage in wildlife-watching activities, they have an impact on wildlife. Mitigating the disruption of wildlife, particularly during vulnerable life-history stages, is critical for species conservation. By continuing to operate through multi-agency, multi-organization task groups, the RWC will facilitate better education and

outreach with clearer objectives and messaging, foster a new ethic of respect for wildlife in all people who live in or visit coastal California, and serve as a model for other programs within California, across the United States, and around the globe.

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REVIEW PAPER

Human impacts on the environment and wildlife in California's past: Lessons from California archaeology

JULIA R. PRINCE-BUITENHUYS[1]*, COLLEEN M. CHEVERKO[2], ERIC J. BARTELINK[3], VERONICA WUNDERLICH[4], AND KRISTINA CRAWFORD[5]

[1] *California Department of Transportation, North Region Environmental, District 3, 703 B Street, Marysville, CA 95901, USA*

[2] *Edward Via College of Osteopathic Medicine – Louisiana Campus, 4408 Bon Aire Drive, Monroe, LA 71203*

[3] *California State University, Chico, Department of Anthropology, 400 West 1st Street, Chico, CA 95929, USA*

[4] *California Department of Water Resources, Division of Integrated Science and Engineering, 3500 Industrial Blvd, West Sacramento, CA 95691, USA*

[5] *University of Nevada, Reno, Department of Anthropology, 1664 N Virginia Street, Reno, NV 89557, USA*

**Corresponding Author: Julia.prince-buitenhuys@dot.ca.gov*

The long history of human-animal interactions in California prior to European contact is frequently not considered when setting ecological baselines and, by consequence, when planning conservation and management expectations and strategies for native species. This article reviews archaeological perspectives that explore the relationship between human niche construction, plant and wildlife populations, and human health in pre-European contact Central California, with an emphasis on the Central Valley and Delta, the surrounding foothills, and the San Francisco Bay Area. A summary of the archaeological record for Central California is provided, along with how niche construction and related evolutionary based models have been used in prehistoric California. Examples of the influences of human niche construction on flora, fauna, and human health from the archaeological and ethnographic record are then discussed. This information is tied to modern wildlife research and management practices that would serve contemporary fish and wildlife management given that human influences on species "natural" habitats and ecological baselines extends much further into the past than current ecological baselines and wildlife management strategies traditionally recognize.

Key words: archaeology, Central Valley, Delta, ecological baselines, environmental management, health, niche construction, San Francisco Bay, traditional management practices

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Conservation practices in California have long recognized how human-wildlife interactions affect the ability of species populations to thrive or decline. For instance, the survival of the giant garter snake (*Thamnophis gigas*), a highly aquatic wetland-marshland dependent snake endemic to the Central Valley of California, is influenced directly by land use practices. As the Central Valley was transformed from native wetland to a patchwork of urban, suburban, commercial, industrial, and agricultural uses, giant garter snake populations also changed. In areas such as the Tulare Basin, where water diversion and development of agricultural crops such as cotton, corn, and grains eliminated the wetland habitat, the species was locally extirpated. In the San Joaquin Valley, much of the wetland habitat was similarly replaced with a variety of agricultural crops such as cotton and almonds, along with urban and industrial development, resulting in severe population decline and fragmentation (USFWS 2017). In the Sacramento Valley, similar land use changes have occurred, but unlike the San Joaquin Valley or Tulare Basin, rice cultivation represents approximately 20% of the regional agriculture production. Here, snake populations have persisted with a less severe overall decline than in the southern parts of the snake's range. The cultivation of rice, often adjacent to patches of remaining marsh/wetland habitat, provides a suitable, albeit less ideal, habitat that provides the summer water regime required by this mostly aquatic snake (Halstead et al. 2014, 2019). To help manage species such as the giant garter snake, ecological baselines are established that underpin conservation and management expectations, planned interventions, and species management standards.

However, recent work in wildlife biology and applied zooarchaeology has increasingly highlighted how modern ecological baselines are inherently biased. These problems often stem from (1) unknown time depth and extent to which humans have modified the environment in the more ancient past, and (2) shifting baseline syndrome, where human perceptions regarding species populations change between generations and within individual lifetimes (e.g., Sáenz-Arroyo et al. 2005; Papworth et al. 2009; Turvey 2009; Wolverton and Lyman 2012; Malhi et al. 2016; Soga and Gaston 2018; Rodrigues et al. 2019). Given these concerns, multiple frameworks have been created to assess the extent to which humans impact populations today; however, many models still struggle to understand the degree to which humans impacted the environment prior to the European colonial period. This time-depth of anthropogenic influence is especially complicated in California, where the ethnographic and archaeological records highlight a rich history where humans actively manipulated the land and influenced species prevalence well before European colonization. Understanding these trends is particularly important for establishing ecological baselines for native Californian species (including food webs), because the ecology of California observed at European contact had been modified and managed by Native Californians for thousands of years.

This review explores the relationships between humans and wildlife in California prior to European contact through the lens of human niche construction, focusing on examples primarily from the San Francisco Bay, the Central Valley and Delta, and the surrounding foothills. We provide a general overview of California prior to European colonization alongside a discussion of theoretical frameworks used by California archaeologists that are relevant to wildlife biology. Drawing from archaeological studies, ethnographic research, and Traditional Ecological Knowledge (TEK), we then provide examples from Central

California on how humans have impacted the spatial patterning of terrestrial species, flora and habitats, the life cycle of terrestrial targeted (e.g., actively hunted and gathered) and non-targeted species, fisheries, and human health and dietary patterns in the past. Finally, we conclude by discussing different ways these concepts might influence present-day fish and wildlife management, particularly the argument that one must consider human influences on species' ecological baselines and habitats. Collaborations between archaeologists and biologists are ongoing (e.g., Rick and Lockwood 2013; Scharf 2014), and this review provides insights into ways archaeology can further inform contemporary conservation management practices within California.

Overview of the Central Valley and San Francisco Bay Area Archaeological Record

Archaeological evidence suggests that the initial settlement of California occurred during the transition from the Late Pleistocene to Early Holocene, approximately 14,000 to 11,000 years ago (Erlandson et al. 2007; Meyer and Rosenthal 2008). During this time, sea levels were at an all-time low and much of the land that currently comprises the California coast would have been inland (Meyer and Rosenthal 2008; Lightfoot and Parrish 2009). Migration into California likely occurred through multiple routes into the interior and along the coast (Erlandson et al. 2007; Lightfoot and Parrish 2009). People from this time until roughly 8500-8000 calibrated (cal) B.C. hunted, fished, and gathered plant resources along coastal areas as well as inland areas with freshwater access (Lightfoot 1993; Erlandson 1994). Between roughly 9050 and 6050 cal B.C., sea levels rose by about 25 meters. Later, between 6050 cal B.C. and 4050 cal B.C., the San Francisco Bay estuary, tidal marshes, lagoons, flats, and protected bays and inlets were formed along the coast and in the California Delta (Rosenthal et al. 2007; Meyer and Rosenthal 2008).

While these large-scale changes in landscape were occurring, Native Californians were mobile and occupied small seasonal encampments instead of year-round villages (Meyer and Rosenthal 1997; Rosenthal and McGuire 2004). They had already adopted practices that would be observed in later historic and modern ethnographic accounts. For example, milling equipment for processing wild plant foods was used as early as 8500-8000 cal B.C. in the San Francisco Bay Area and foothills of the Central Valley (Milliken et al. 2007; Meyer and Rosenthal 2008; Hildebrandt and McGuire 2019). There is also archaeological evidence that Native Californians harvested wild plant foods such as acorn, piñon, and wild cucumber (Meyer and Rosenthal 1997; Wohlgemuth 1997; Rosenthal and McGuire 2004). Evidence of stone tools sourced from far-away quarries throughout the Central Valley and Bay Area and the presence of California coast marine shells found in the Great Basin dating to 5500 cal B.C. reflect widespread trade networks across different regions of California (Bennyhoff and Hughes 1987; Meyer and Rosenthal 1997; Fitzgerald et al. 2005; Milliken et al. 2007; Rosenthal et al. 2007). By 4050 cal B.C., Central Valley groups were more sedentary, although seasonal high-mobility foraging was maintained in the foothills.

From 3500 cal B.C. to about 550 cal B.C. in the Valley and lowlands of the Bay Area, there were notable shifts towards sedentism, which included intensive use of local resource patches. Regional trade increased, mortars and pestles were adopted as more common tools alongside milling slabs, and people used ornamental items such as cut *Olivella* and *Haliotis* beads. Graves with high levels of ornamentation are found inside shell and earthen mound sites (Meyer and Rosenthal 1997; Milliken et al. 2007; Rosenthal et al. 2007). These constructed mounds, like the West Berkeley Mound (CA-ALA-307) and the Blossom Mound

(CA-SJO-68), are among the oldest examples of shell and earthen mounds located in the San Francisco Bay Area and California Delta, respectively (Lightfoot and Luby 2002; Luby et al. 2006; Moratto 1984). Most important to discussions of wildlife management, faunal assemblages from these sites suggest Native Californians relied on a mosaic of resources from different habitats, especially the San Francisco Bay, freshwater and saltwater marshes, riparian forests, and grasslands (Broughton 1994a; Meyer and Rosenthal 1997; White 2003a,b).

Starting around 550 cal B.C., there was a shift toward a cooler, wetter climate and less saline conditions in the Delta (Meyer and Rosenthal 2008). Many new specialized technologies became more common, and food economies shifted toward seasonal resources that could be bulk harvested, stored, and processed as staples, such as acorns (Basgall 1987; Wohlgemuth 1997, 2004; White 2003a,b). This trend became more notable through time until European contact. Furthermore, the presence of mound sites increased and expanded into the lower Sacramento Valley during this period, with a southern boundary of the lower foothill woodlands of the San Joaquin Valley (Schenck and Dawson 1929; Rosenthal et al. 2007). These mound sites contain remains of habitation structures such as hearths and house floors, extensive deposits of habitation debris, and burials, all of which suggest they may have served as large permanent and semi-permanent village centers that were occupied year-round or seasonally (White 2003a; Rosenthal et al. 2007). The distribution of mound sites was widespread, with ethnographers and archaeologists estimating that mounds were located approximately every two to three miles along the Sacramento River (Schenck and Dawson, 1929).

Native Californians experienced major periods of environmental change from A.D. 1000 until European contact. For example, this period includes the Medieval Climatic Anomaly (MCA), during which Native Californians experienced two punctuated periods of drought, higher average temperatures, and increased fire activity (Meko et al. 2001; Marlon et al. 2012; Meyer and Rosenthal 2008). Another severe drought occurred in the Sacramento watershed around approximately cal A.D. 1530 (Meko et al. 2001).

During this time period of environmental shifts, the density of archaeological sites increased and population estimates were some of the highest in Native North America (Cook 1976). Additionally, the bow and arrow were introduced, replacing the atlatl as the preferred hunting tool (Bettinger 2013). Fish weirs were constructed along rivers and streams near some of the larger mounds located in the northern Central Valley, where river corridors were narrower (Sundahl 1982; White 2003a). Villages and smaller camp sites were still common along river channels, sloughs, and other bodies of water (Schenck and Dawson 1929; White 2003a; Rosenthal et al. 2007). Harvesting of wild plants and fishing increased in importance, and archaeological evidence suggests that terrestrial species targeted for hunting were diverse and hunters increasingly focused efforts on smaller prey species (White 2003b; Wohlgemuth 2004).

By the late 1770s, California's Native population began to decline, likely caused in part by the introduction of infectious diseases by European settlers, which likely spread to Native Californians prior to the Mission Period (Preston 2002). Infectious Diseases such as syphilis and gonorrhea introduced to Native Californians continued to decimate populations through the Spanish Mission system (Jackson 1994; Preston 2002; Jackson and Castillo 2005). The Spanish Mission system subjected Native Californians to exploitative working conditions, poor quality diets, poor sanitation, and squalid living conditions at the missions throughout the California coast (Jackson 1994; Jackson and Castillo, 2005; Sandos 2008). Additionally, it functioned to erase social connections and the culture of Native Californians by convert-

ing them to Christianity, breaking up family groups by sending people to missions far from home, and forcing labor, agricultural, and ranching practices on people so they could not as easily practice their own native foodways and culture (Jackson and Castillo 2005; Sandos 2008). Missionization also started the conversion of lands and the environment toward the landscape we see today by introducing non-native and invasive species, including European rodents and grasses alongside agricultural and livestock products such as cattle and wheat (Chartkoff and Chartkoff 1984; Anderson 2005). While the Mission system had a negative impact that continues to influence communities today, it is important to highlight that Native Californians mounted resistance in many ways, enabling them to maintain much of their culture and lifeways (Castillo 1978; Jackson and Castillo 2005; Akins and Bauer 2021).

When the United States assumed control of California and the Gold Rush began in 1850, genocide and cultural erasure were accelerated and expanded to places in the interior where Spain and Mexico had not previously focused colonization efforts. Mining, lumbering, and agricultural practices as well as development of infrastructure like levees and urban construction led to modified waterways, marshes, meadows, forests, and grasslands (Starr 1980; Carle 2004; Anderson 2005; San Francisco Estuary Institute 2008). At the same time, Native Californians faced massacres, bounty hunting, enslavement, forced assimilation, and forced removal from ancestral homelands (Castillo 1978; Lindsay 2015; Madley 2017). In removing the Native Californians who managed their landscapes, the ecological patterns and discussion about what should be considered "normal" ecology changed through time. As a result of this history, both Native Californians and the native environment of California have been drastically transformed by Euro-American occupation.

Niche Construction Theory and California Archaeology

Since the 1980s, human behavioral ecology theory (HBE) has played a prominent role in California archaeology (Broughton 1999). Within HBE, optimal foraging theory (OFT) models predict a relationship between prey body size and energy gain, often framed using prey-rank or diet-breadth models (MacArthur and Pianka 1966; Schoener 1971; Charnov 1976). The diet-breadth model posits that human foragers will attempt to harvest the maximum net energy gained while hunting game with as little energy expended as possible. These models predict that human foragers in Late Holocene central California attempted to maximize energy gain relative to search costs during hunting forays and thus selected higher-ranked, large game resources over lower-ranked, smaller fauna regardless of their abundance on the landscape (Broughton 1999). When high-ranked prey items are significantly depleted within a local resource patch, foragers will select the next highest ranked prey item (i.e., diet-breadth expansion) or instead will focus efforts on more distant resource patches (MacArthur and Pianka 1966; Charnov 1976). Over time, declines in the relative abundance of high-ranking, larger prey relative to lower-ranked, smaller prey because of overhunting (i.e., resource depression) would signify a reduction in foraging efficiency (Bayham 1979; Broughton 1994a, b, 2002).

The diet-breadth model also predicts greater investment in lower-ranked plant resources and the technology used to process them as higher-ranked game resources are depleted from local resource patches (Basgall 1987; Wohlgemuth 1996). When tested in archaeological contexts, these approaches are framed as resource intensification models and used to predict temporal declines in the relative abundance of large game relative to lower-ranked resources (e.g., smaller game and wild plant resources), as tracked through archaeofaunal, archaeobo-

tanical, and artifact assemblages (Basgall 1987; Broughton 1994a, b; Wohlgemuth 1996). In pre-European contact California, intensification models predict diet-breadth expansion marked by the increased investment in wild plant resources and lower-ranked fauna, reflecting a decrease in foraging efficiency (i.e., increased energy expenditure relative to caloric gain) and a decline in human skeletal and dental health (Broughton 1999; Bartelink 2006; Broughton et al. 2010; Bright and Bartelink 2013; Prince-Buitenhuys and Bartelink 2020).

In the Sacramento-San Joaquin Delta and San Francisco Bay Area, archaeologists have proposed that resource intensification played a role in the development of intensive acorn storage economies, greater use of small seeds, and greater investment in anthropogenic burning of the landscape (Broughton 1999, 2002). Evidence from numerous archaeological sites indicates that Native Californians increased their reliance on acorns and certain types of small seeds through time (Basgall 1987; Wohlgemuth 1996; Broughton 1999). In California, Late Holocene population growth is associated with increased sedentism, which in turn contributed to depression of local resource patches (Testart et al. 1982; Broughton 1999). Diet-breadth expansion continued into the late precontact period, although a post-Euro-American contact rebound in large game populations has been documented in several archaeological contexts in the western US, likely resulting in part from a decline in the Indigenous population following European incursion into the area (Preston 1997, 2002; Butler 2000; Broughton 1999).

Niche construction theory (NCT) has recently been applied to further understand human-wildlife interactions in California history (Broughton et al. 2010; Prince-Buitenhuys and Bartelink 2020). Niche construction is an evolutionary process where organisms create or modify their own niche, which in turn may influence selective pressures for future descendants of that species and other species in the same ecosystem (Odling-Smee et al. 2003, 2013). This ecological inheritance can influence the effects or direction of natural selection. Archaeologists have recognized the compatibility of NCT and resource intensification models and their predictive power to explain how humans altered environments in Late Holocene California (Broughton et al. 2010; Riede 2019).

The pre-European contact record of Native Californian land use patterns demonstrates how environmental niches for native plant and animal species were anthropogenically altered and managed by Native Californians. Understanding the human-influenced pre-European "natural" landscape has major consequences for how we conceptualize baseline data (e.g., foodwebs) for managing species in modern environmental studies, including the kinds of environmental strategies that provide effective outcomes for plant and animal communities. Because the ecology of California observed at European contact was modified by Native Californians, the concepts about what constitutes the baseline of plant and wildlife populations are at least partially dependent on humans actively manipulating habitats. In other words, what is now considered "natural" as the baseline is different from the plant and animal communities managed by Native Californians.

Examples of Human Niche Construction Impacts on Ecology

Human influences on flora distribution.—Niche construction practices of Native Californians, especially within Central California, relied on the long-term management of resource patches such as oak trees, groves, or meadows, which influenced the presence of managed and unmanaged habitats across the landscape. The ethnographic record describes how many tribes held ownership rights based on resource management over specific lands

and resources. This form of ownership provided families, individuals, and communities with exclusive rights to specific resources (Anderson 2005). Discrete patches owned by a group were marked by boundaries and could be inherited for generations through kinship and marriage. These managed areas were maintained through irrigating, weeding, burning, tilling, and pruning to maximize their abundance and productivity to meet cultural needs, including food resources and basket-making materials (Anderson 2005; Goode et al. 2018).

In archaeological contexts, these practices have been explored in relation to the use of anthropogenic burning for maintaining specific grassland habitats and maximizing harvests of key food resources. Plant foods such as acorns, piñon, berries, and roots, as well as wild game such as deer and elk, thrive within a managed fire regime based on archaeological evidence, ethnographic accounts, and modern ecology studies (Anderson et al. 1997; Anderson 2005; Keeley 2002; Lake 2013). Controlled burns aided in food resource productivity while also providing conditions conducive to the growth of plants used for cordage, baskets, nets, granaries, clothing, hunting and fishing implements, and weapons (Anderson 2005, pp. 136-137). In addition, fire was used to reduce the density of dead trees, grasses, and thick undergrowth to lower wildfire risk, create trails and corridors between resource zones and communities (Lake 2013), provide protection from outsiders and enemies (Keeley 2002), and aid in hunting (Anderson 2005).

The use of fire before European contact provides an example of how human niche construction helped maintain grassland and fire reliant flora to improve resource harvesting. For example, Keeley (2002, 2005) found that anthropogenic burning was instrumental in converting landscapes from shrubland to grassland along the North and South Coastal Ranges prior to European contact. In a study that examined fire regimes in the east San Francisco Bay Area during the 19th century, Keeley (2005) found that natural fire regimes (e.g., fire from lightning strikes) cannot explain the long-term success of grasslands and further that shrubs would colonize grasslands without regular disturbance through human-started fires removing woody vegetation and/or heavy grazing and browsing. He goes on to argue that the population density in the East Bay (100 villages with over 2000 inhabitants) would have significantly impacted the size of herds of grazing and browsing species like deer and elk and that regular human-started fires would have been required to expand and sustain grasslands in the Bay Area (Keeley 2005).

The frequent use of anthropogenic burning is consistent with the findings from paleobotanical and phytolith studies at CA-SMA-113 in the Quiroste Valley, between ca. cal A.D. 1000-1300 (Cuthrell 2013). Charcoal analyzed from the site included very few fire-susceptible trees and shrubs, such as Douglas fir (6.4% of the charcoal assemblage), suggesting that those were not a common resource in the region. Instead, redwood, California lilac, and alder was significantly more prevalent in the charcoal assemblage (73.7%). Redwood is extremely resistant to fire, and California lilac germinates in response to fire, suggesting their prevalence over fire-susceptible species such as Douglas fir and Coyote Brush was due, at least in part, to regular burning of the landscape (Cuthrell 2013). Most importantly, human-preferred resource bearing species that have harvests enhanced by fire were also prevalent. California hazel was the most common edible nut species identified (85.5% by weight of the edible nut assemblage), and ethnographically is known to have been regularly burned by native peoples to produce more sprouts and nuts (Anderson 2005; Cuthrell 2013). Additionally, grass and forb seeds from species common to grasslands composed most of the seed assemblage (57.5%), in line with expectations for a pre-European contact anthropogenically managed grassland landscape as predicted by Keeley (2002, 2005).

The pattern of fire evidence over the past 3,000 years in California shows that fire prevalence and climate change were correlated before A.D. 1880, with evidence for increased fire activity during the Medieval Climatic Anomaly drought periods and a decline in fire during the wetter Little Ice Age (Marlon et al. 2012). While current data cannot be used to determine how much burning was from human activity versus lightning strikes before the 1800s, both likely contributed to the ecology and managed resource patches present at European contact (Keeley 2002; Lake 2013; Lake et al. 2017).

During the late 1800s and early 1900s, the United States dramatically changed fire management in the West. While in the 1800s there was an increase in fires, fire suppression regimes such as that initiated by the US Forest Service in 1905 caused a build-up of fuels, a problem that continues to this day (Marlon et al. 2012). These new fire management practices ultimately led to long-term changes in wildfire patterns in the region. For example, the elimination of fire management activities such as the low-fuel, small-scale controlled fires used by Native Californians resulted in fundamental changes in the structure of forests, which historically included a mixture of tree density and size with a more open canopy structure, to a dense vegetative understory with a more closed canopy. These changes allowed for an overgrowth of plant species that thrive without fire like invasive weeds, decreased tree health which allowed the introduction of disease and pest species, and accumulation of fuel load that contributes to hotter fires that tend to kill fire-adaptive native tree species (Stephens et al. 2018). These changes in management strategies also resulted in the spread of juniper and sage into old-growth forests that invade habitats where high-heat wildfires have killed off trees and plants that would otherwise be maintained and even thrive with a regular low-heat fire regime (Anderson 2006).

In contrast to practices allowing increased spread of non-native species, recent studies have found that regular human-induced burns in areas where habitats, such as those in which vernal pools originally thrived, can help revive and rehabilitate native plant communities (Pollack and Kan 1998; Ditomaso et al. 2006; Cook and Hayes 2020). Similarly, using fire for clearing facilitates maintenance of different environmental patches (e.g., woodlands, meadows). The use of controlled burns is recognized as an effective management strategy for reducing the intensity of wildfires experienced recently in California (Anderson 2005, Lake 2013). Landscape management using small-scale prescribed burns could be worthy areas of collaboration between interested tribal parties, wildlife biologists, ecologists, and archaeologists to create better management practices for recovery of meadows and other habitats in regions they thrived in pre-European contact California.

It is worth noting, however, that local ecology, preferred resource patches and types, and even the impacts of climate through time all vary according to the region, and human niche construction had its limits. In the lower Sacramento Valley, for example, the resources exploited look very different than the patterns at CA-SMA-113 and other sites from the Bay Area and foothills. In the lower Sacramento Valley, represented by village sites CA-SAC-485 (550 cal B.C. – cal A.D. 150), and CA-SAC-15 (cal A.D. 580 – cal A.D. 1510), Themidaceae family geophyte corms were intensively used, a pattern distinct from dozens of other sites in the Bay Area and Central Valley outside of the lower Sacramento Valley (Wohlgemuth 2016). Furthermore, while both acorns and small seeds were intensified in the Sacramento Valley and the Bay Area, the pattern of intensification is slightly different; small seeds were found in extremely high densities at the two Sacramento County sites, with the increased prevalence (and predicted intensification) starting at least 2500 years ago (Wohlgemuth

2004, 2010, 2016). CA-SAC-485 and CA-SAC-15 did not have as reliable of nut resources as other regions in the foothills and the Bay Area, as Valley Oaks were the only source of edible nuts and those rank low as resources compared to black or blue oak (Wohlgemuth 2016). Given this, context-specific research into past trends are important to understand how the mosaic of habitat patches functioned pre-European contact and the nature of resources targeted by human communities. This information will likely impact which species directly and indirectly benefited, and which were suppressed, in any given region.

Terrestrial fauna, buffer zones, and edge habitats.—Gathering areas were specialized niches similar to tended gardens that patterned the landscape with wilds, trails, and waterways in between them. These practices helped maintain a complex patchwork of microenvironments that influenced the variety of game and plant resources available within a daily foraging radius of a village site (Broughton 1994a, 1994b; Lightfoot & Parrish 2009; Broughton et al. 2010). However, these practices could also result in localized resource depression of some game species within these managed areas, depending on strategies employed and local population density.

The establishment and maintenance of patches would have created a series of anthropogenic edge habitats likely used by many target and non-target wildlife species in pre-European California. The use of anthropogenic and naturally-occurring edges has been demonstrated in various species ranging from large carnivores such as grizzly bear (*Ursus arctos horribilis*) (Stewart et al. 2013), which is now extirpated from its former range in California, down to small invertebrates such as ground beetles (Magura and Lovei 2020). Depending on the techniques used to maintain these edges, dispersal and use of the habitat could potentially vary from that of naturally occurring edges and result in modified species assemblages in the anthropogenic edge as compared to the naturally occurring edge. Linear anthropogenic edges could also have supported a higher diversity of plant species (Suarez-Esteban et al. 2016) and provided additional desirable plants beyond those maintained within the patches. In modern times, this edge-related plant diversity and abundance can potentially favor non-native or exotic species (i.e., plant species that were not present at the time of European contact).

These resource patches with inherited rights and established seasonal or annual camps and villages meant that territory was extremely important and relevant in Native California, even though it was not conceptualized in the same way as Euro-American ownership. People maintained their own gardens, fishing spots, and hunting grounds so they could maximize the range of available resources, especially as higher-ranked, larger fauna were depleted locally. Some archaeologists have theorized that because of the mosaic of maintained patches and variety of resource access, Native Californians were able to maintain higher population density circa-A.D. 1000, mitigating the effects of resource depression (Broughton et al. 2010). These patterns are predicted to have led to increased defense of territories and the creation and maintenance of buffer zones, which are defined as areas between territories that may have been used as hunting grounds but that also served as areas where adjacent groups could minimize interaction and, therefore, prevent conflict (Bayham et al. 2012, 2019).

Areas located between these gathering patches would effectively become buffer zones with reduced hunting pressure on species that would have been targeted within the gathering areas. These zones would function as refuges for those species, allowing for increased survival of individuals compared to those that remained within the gathering areas. Behavioral avoidance of gathering patches during times of high hunting pressure would reinforce the

function of these spaces. This behavioral avoidance of areas with high hunting pressure is seen today in a wide variety of species such as northern pintail (Casazza et al. 2012) and red deer (Lone et al. 2015). For example, studies have shown shifts in distance traveled and exploratory behavior in white-tailed deer (*Odocoileus virginianus*; Marantz et al. 2016) and an increase in distance from roadways, use of cover, and vigilance behavior of elk (*Cervus elaphus*; Paton et al. 2017, Cleveland et al. 2012) during times of increased hunting pressure. These behaviors allow the species to better avoid predation and unwanted encounters with, for example, vehicle traffic.

These patterns of buffer zones and managed spaces likely had significant consequences for the outcomes of populations of species prehistorically. For example, the Tule elk from the Emeryville area likely underwent a population bottleneck starting around approximately cal A.D. 350 based on ancient DNA studies from the Emeryville Shellmound (CA-ALA-329) (Broughton et al. 2013). OFT models previously predicted that Tule elk underwent resource depression due to changes in the relative abundance of elk compared to other, lower ranked prey species, and this predicted pattern is reflected in the "Elk Index" across sites along the San Francisco Bay shoreline (Broughton 1994b, 1999; Broughton et al. 2013). The lack of variation in carbon, nitrogen, and oxygen isotopic values through time for the Tule elk from Emeryville further suggests that climate change is unlikely to be the cause of this variation (Broughton et al. 2013). Given this, it seems likely humans hunted Tule elk so intensely that it resulted in a population bottleneck, but the population was able to survive despite intensive hunting pressure. This is in contrast to sea otters found in faunal assemblages around Bay Area sites after cal A.D. 1 (Broughton 1994a; Milliken et al. 2007), which were hunted heavily pre-European contact but did not experience a genetic bottleneck event even during heavy fur trades of the 18th through early 20th century (Larson et al. 2012).

Similar to patterns observed for wild plant collection and use, however, it is once again important to remember these generally described patterns of systems are specific to species and location. A study of the relative abundance of artiodactyl remains at the Emeryville Shellmound compared to other common lower ranked fauna in the collection (for the Bay Area – sea otters) has found that artiodactyl remains are less common through time in the region (Broughton et al. 1994b). In comparison, the Sacramento Valley data show minimal resource depression of artiodactyls when comparing their remains to small fish and also to lagomorphs and rodent species, but the trend in the Sacramento Valley examines freshwater and anadromous fishing compared to hunting and trapping of terrestrial mammals (Broughton 1994a; Broughton et al. 2010). These patterns do not translate across studies however, even using the same indices. Other studies examining the general trends of artiodactyl indices throughout Central California have suggested that deer, elk, and pronghorn in the rest of California were not over hunted and even underwent population increase through the Holocene (Codding et al. 2010; Whitaker et al. 2019). Examination of sites throughout the Bay Area have also found evidence that the trends for artiodactyl hunting observed archaeologically tend to vary between microhabitats (Milliken et al. 2007).

Given this variability of species hunting and prevalence across locations and time, it is extremely challenging to estimate baseline data for a species population such as Tule elk or other artiodactyls. Human influences are likely strongly tied to past population bottlenecks and the patterning of buffer zones and habitat patches across the state, especially in areas that exhibited high population density before European contact. California archaeologists are regularly expanding zooarchaeological data sets through Cultural Resources Management studies, and faunal collections are housed in museums and curation facilities across

the state that have not been exhaustively studied. This means there is potential for many forms of studies with many available data sources. However, much of this zooarchaeological data are in confidential reports that can be difficult to access, and even when accessed not all reports use the same collection/sampling strategies or analytical methods. Given this, collaboration with archaeologists is key to conducting applied zooarchaeological studies for conservation management purposes.

Fishing patterns before European contact.—Another important case study is understanding precontact fishing patterns in California, especially the use of salmon as a key source of protein. Isotopic, zooarchaeological, and ethnographic data provide a rich and important record of this practice (Broughton 1988, 1994a; Yoshiyama et al. 1998, 2001). Salmon bones are rare in archaeological sites from the Delta and mid-Central Valley, but they are more abundant in foothill sites adjacent to the Valley where the creeks and rivers become narrower and shallower and in the upper reaches of the Sacramento River in the northern Sacramento Valley (Broughton 1988, 1994a). The increase in the relative abundance of salmon relative to smaller resident fishes with latitude does not appear to be a taphonomic issue and is corroborated by an abundance of salmonid bone and stable carbon and nitrogen isotope evidence on human skeletons at the Abbott Site (CA-SHA-1043), located along a narrow section of the Sacramento River (Hildebrandt and Darcangelo 2007; Bartelink et al. 2017). Like marine and estuarine fish, salmon feed from marine resources and carry a high trophic-level marine isotopic signature into freshwater streams and rivers of the Central Valley when they migrate and spawn. At the Abbott site, carbon and nitrogen isotope data from human bone collagen reveals that, on average, 29% of the dietary protein consumed by people derived from salmon, compared to several archaeological sites in the mid-Central Valley and Delta region, where salmon likely contributed only about 13% of the dietary protein consumed (Bartelink et al. 2017). The isotopic signature of individuals at SHA-1043 more closely resemble coastal people, whereas individuals from sites along the Sacramento River and its tributaries near modern-day Sacramento and Stockton consumed freshwater fish and terrestrial mammals as their main protein source.

The zooarchaeological record of SHA-1043 supports these results. The faunal record is nearly evenly split between mammals representing 48% and fish representing 49% of the total assemblage. Combined, salmon and steelhead represent over half of the total fish assemblage, and Sacramento suckers and minnows like Sacramento pikeminnow and hardhead represent 29% and 26% respectively (Garibaldi and Hildebrandt 2007; Hildebrandt and Darcangelo 2008). This evidence suggests salmon were not mass-captured (and therefore were underutilized) in much of the mid-Central Valley and Delta until they got far enough upstream to spawn.

It appears that smaller bodied freshwater fishes were targeted instead of salmon in the lower Sacramento Valley and Delta during the past 1,000 years (Schulz and Simmons 1973; Schulz 1979; White 2003a; Miszaniec et al. 2018). Fishes, including Sacramento perch, hitch, splittail, Sacramento blackfish, tule perch, and thicktail chub, are most common in slow water habitats like oxbows, pools, and marshes which are common in the region (Schulz and Simmons 1973; Moyle 2002). The fish assemblage at two sites in Contra Costa County, CA-CCO-138 and CA-CCO-139, was dominated by cyprinid remains (n = 688), however only 26 individual specimens were identifiable to species (Miszaniec et al. 2018). Of the remaining fish assemblage identified to species, Sacramento perch dominated with 338 individual identified specimens, followed by 33 sturgeon elements (Miszaniec et al. 2018). Additionally, 51% of the total identified fish at the Stone Lake site in Sacramento

County were Sacramento perch, with 86% of the total fish identified being slow water species (Schulz and Simmons 1973). Nearly 98% of the fishes recovered at CA-COL-1, the Patwin village *Tsaki* which was occupied into the Historic era, were slow water species (Schulz 1979). At this site, Sacramento perch accounted for nearly 25% of the total; however, thicktail chub, which were considered extinct as of 1957, dominated the assemblage at 41% (Schulz 1979; Moyle 2002). Just north of CA-COL-1, several sites along Highway 45 not only exhibit increased use of fish through time especially after A.D. 770, but they also demonstrate increased use of slow water fishes (White 2003a; Rosenthal et al. 2007). While Sacramento perch was abundant in the slow-water fish assemblage at these sites, sturgeon and salmon species were also recovered in large quantities (White 2003a). Combined, the trends of fish use at archaeological sites in the Central Valley reflect the general animal and plant exploitation trends of the past 1,000 years. These examples highlight how there is not a one-size-fits-all pattern or strategy that can be used to describe all of California.

Evidence of fishing technology can also be used to infer general patterns of fishing activity before European colonization. However, fish harvesting technology is largely constructed with soft materials like textiles and wood, which are usually not recovered in archaeological contexts (Rosenthal et al. 2007). The primary evidence of fishing technology is stone net weights and sinkers, hafted biface knives for descaling and cutting, and occasionally bone harpoon points, gorges, and hooks (Bennyhoff 1950; Kroeber and Barrett 1960; Hester and Follett 1975). Facilities constructed to aid in harvesting such as dams, weirs, traps, and fishing platforms are constructed in stream channels and are off-site fixtures that, if they survived, may be overlooked during archaeological investigations (Rosenthal et al. 2007). These facilities were temporary in nature and therefore did not permanently block fish from their upstream spawning grounds (Kroeber 1925; Heizer 1978; Anderson 2005; Goode et al. 2018). The increase in plant and fish harvesting and the soft technologies used for procuring and processing both may in part explain the reduction in stone tools recovered from village sites that date after A. D. 770 (Rosenthal et al. 2007).

Impacts of niche construction and resource depression on human diet and health.—In addition to impacts on wildlife, human niche construction can impact human health and diet. Archaeological studies of ancient human health and paleodiet often rely on the biocultural approach (e.g., Zuckerman and Martin 2016; Cheverko et al. 2020), which recognizes that human environments consist of ecological, physical, and cultural components that include social groups, large communities, and every-day influences on human lives such as social norms, rules, guidelines, interpersonal relationships, and community behaviors (Prince-Buitenhuys and Bartelink 2020). As such, culture can act as a buffer to lessen impacts of external stressors, but it can also induce stressors that might not otherwise exist in a given ecological setting (Prince-Buitenhuys and Bartelink 2020). Importantly, this biocultural approach and NCT framework can be used to generate testable hypotheses, such as whether the prevalence of skeletal indicators of health increase or decrease in a specific environment. When applied to precontact Central California, NCT can be used to predict that resource depression and the development of acorn storage economies resulted in an overall reduction in dietary quality that negatively impacted human health, marked by increases in the prevalence of non-specific indicators of stress (e.g., stature reduction, periosteal bone lesions, enamel hypoplasia, scars of anemic response, etc.) and changes in diet through time (Bartelink 2006; Broughton et al. 2010; Prince-Buitenhuys and Bartelink 2020). For the Sacramento-San Joaquin Valley in particular, Late Holocene trends suggest a decline in skeletal health, marked by a temporal decline in stature and an increase in enamel hypoplasia

defects, periosteal bone lesions, and scars of anemia (i.e., cribra orbitalia; Bartelink 2006; Broughton et al. 2010).

There is ample information about past human health and paleodiet based on the Marsh Creek (CA-CCO-548) site, located in present-day Contra Costa County in a transitional zone between the San Francisco Bay and California Delta (Wiberg 2010; Bartelink et al. 2020). Stable isotope analysis of human burials from this site suggests a dietary emphasis between the diets of individuals consuming freshwater and terrestrial resources in the Delta and individuals consuming more marine resources in the San Francisco Bay Area (Bartelink et al. 2020). While the relative protein source remained stable through time at Marsh Creek, there was an increased reliance on wild C_3 plant resources through time, consistent with resource intensification models (Bartelink et al. 2020). In addition to dietary data, studies of human health (using physiological stress indicators as a proxy) from Marsh Creek demonstrate that individuals experienced high rates of dental attrition and low rates of dental caries (Griffin 2014), especially compared to other contemporaneous sites (Kolpan and Bartelink 2019). These differences in oral health indicators might be explained by dietary composition, cultural behaviors such as using teeth as tools, and the influence of certain plants on the oral biofilm that inhibit the development of dental caries (Griffin 2014), highlighting how the combination of cultural and environmental factors influenced human health in the past. Taken together, the paleodiet and dental health information support assertions that locally constructed niches impacted the food resources utilized within that environment, which contributed to patterns of human health.

The Canyon Oaks site (CA-ALA-613/H) provides a second case study in which one can interpret the effects of environmental change using an NCT lens, because the site was continuously occupied for a period of about 3600 years, including before, during, and after a period of extreme drought during the MCA (Pilloud 2006). The temporal span of this site allowed for a diachronic study of human remains to understand whether markers of skeletal stress and disease increased during the period of environmental instability as would be predicted during times of environmental stress. The prevalence of dental caries declined in males through time, but significantly increased in females during the MCA before declining again afterward. Another stress indicator, linear enamel hypoplasias (LEH), form on teeth during enamel formation and occur as linear bands of deficient enamel caused by physiological stress (e.g., malnutrition, infectious disease). While the prevalence of LEH may have increased during the drought period, there were no significant diachronic changes in LEH overall or in stature or interpersonal violence between the three periods (Pilloud 2006), providing variable evidence for drought-related effects on human health. Pilloud (2006) concludes that individuals living at this site developed new cultural practices such as new subsistence strategies to help them mitigate the environmental pressures they faced, and that some of these strategies may have varied by sex. This study concluded that culture may have buffered individuals against physiological stressors associated with adverse environments. In comparing the patterns observed at this site compared to contemporaneous sites, it is clear that drought did not affect all individuals and populations the same way (Pilloud 2006; Jones and Schwitalla 2008; Schwitalla and Jones 2012).

These two case studies demonstrate how bioarchaeological research uses inferences from human skeletal remains to provide insights into past human-environment interactions and the symbiotic effect of the environment and culture on ancient health. As demonstrated by health patterns from these archaeological sites and others, complementary lines of evidence from the San Francisco Bay Area and California Delta present variable histories

of diet and health that are intrinsically linked to the local environment; thus some patterns cannot be generalized across regions or time periods. Variation in cultural and physical environments steered local health and dietary patterns in Central California, both within and between environments, with human constructed niches impacting these patterns on local levels. Concurrently, interactions between Native Californians and their environments led to further alterations of these niches, especially on local levels.

Lessons for Contemporary Species Management

California's ecological norm has been a managed landscape in both the past and present. The natural resources and wildlife of California have been managed by humans for at least the past 13,000 years. For thousands of years, Native Californians have manipulated their environment and constructed niches as a form of biocultural adaptation, and these niches have influenced the evolution and adaptations of future generations. Given the time depth of California's archaeological record, the dynamics between humans and other species, flora and fauna alike, have been complex. While they have led to periods of stress on some populations of species such as artiodactyls, they have helped others such as trees and brush that thrive in low-heat fire. People living in different regions were affected by environmental changes, resource availability, and population growth in a myriad of ways, none of which are easily generalized across Central California. What follows are three important lessons and considerations for contemporary wildlife management.

1. There has been no "natural" California without human presence for millennia.

It is important to remember that one of the fundamental assumptions that came with European colonization was the belief that the land was somehow "untamed", "pure", or "wild". In other words, they assumed it was free from significant human influence. However, Native Californians successfully managed their landscapes in ways that provided benefits for them and their target flora and fauna species, leading to altered landscapes shaped by the people who lived there.

Nevertheless, several new management practices were enacted following European contact that were based on the assumption of an untamed landscape, including movements for fire suppression starting in 1905, environmentalist movements starting with naturalists like John Muir, and attempts to end logging altogether in the 1970s. These practices combined to form long-term impacts on the environment. Similar policy decisions and misunderstandings at times by the scientific community about the relationship of California's naturally human landscape have led to decreased abundance of once common species, reduction in habitats of species that thrive with regular low-heat burn regimens, and an increased prevalence of non-native species and species that thrive without managed landscapes that would otherwise suppress them, such as poison oak and thistle, or in some areas of the Bay shrubland and Douglas Firs.

Given these factors, estimations of ecological baselines and assumptions about population histories for species in California should take into consideration the roll humans have played prehistorically in manipulating the environment and influencing the species in question. If models underpinning management plans, population prevalence, and more start from some base assumptions that human influence is a natural part of the species history, that would be a benefit. However, an even bigger benefit may be incorporating data from the archaeological record regarding the species in question, and conducting studies on

archaeological resources to better understand the relationship of the species with humans, animal migration routes, species genetic diversity in deep time, and even the kinds of human induced or human related pressures the species has experienced before in different contexts.

2. Human cultural patterns have a large impact on local environments.

Even prehistorically, human management decisions, such as what resources to target and which resources were valuable had important roles in changing the outcomes of species. Tule elk underwent a population bottleneck in the Bay Area potentially due to overhunting. Meanwhile, sea otters were unaffected despite their heavy exploitation, yet artiodactyl populations were reduced at the Emeryville Shellmound, while other artiodactyl species in other regions did not experience the same level of hunting pressure. Some strategies even served the interest of species; salmon fishing occurring primarily in the foothills and the use of temporary dams and weirs helped the fish have access to spawning grounds and opportunities despite human predation, for example. Given the wide-ranging consequences of humans on habitats and other species, it makes sense to consider even more critically the kinds of roles humans had for specific species in different environments and regions throughout California when trying to establish an ecological baseline for management purposes.

Another important point is that the use of strategies (e.g., maintained patches, buffer zones, anthropogenic burning, and weir use) for landscape management also involve multiple specific cultural and behavioral attitudes and habits that sustain them. Burning as a practice is an excellent example because tribal groups and families who tended their own areas were responsible for burning their local landscapes prior to European colonization, as opposed to the large organizations and agencies responsible for organizing prescribed burns in contemporary management practices. This concept of localized land management responsibility is slowly being re-implemented in California today through a variety of programs that build collaborations between tribal partners and state, local, and federal entities (Lake et al. 2017; Goode et al. 2018). If people are trained to conduct small-scale controlled burns in an environmentally responsible fashion, they will be able to decrease fuel loads, reduce risks of catastrophic wildfires, improve the health of ecosystems in which native species thrive, and provide better outcomes for society. This initiative requires a societal change toward the use of anthropogenic burning, with improved collaboration, communication, and coordination between tribes, agencies, government, and local landowners (Lake et al. 2017; Rougle 2019). It also requires the creation and maintenance of easily accessible training opportunities for people to learn how to conduct safe prescribed burns. In turn, other downstream benefits include the development and maintenance of vegetation overgrowth, the creation of better soil for crops and some native species of interest, and the reduced risk of homes being destroyed during mega-fires. In addition, governments at all levels could work alongside community organizations to provide financial incentives for developing programs aimed at furthering research, learning opportunities, and chances to implement land management strategies (Lake et al. 2017; Rougle 2019).

3. Human involvement in environmental management can impact human outcomes.

Archaeological evidence supports the argument that Native Californians were able to influence their own health by adopting new technology and developing other cultural practices that helped them further establish their niches within localized environments. This resilience is not new, did not always involve idyllic outcomes for people or wildlife, and did not result in universal patterns between micro-environments or regions. Similar to the floral

and faunal data from pre-European contact California, variable outcomes and patterns of health have been observed at different archaeological sites in Central California. However, this basic concept that people can adapt to their environment while simultaneously altering their environment continues into the modern day and is part of California's natural history.

Some of the practices that were used for managing species recorded in the ethnographic record were present and used before European contact, based on the archaeological record. These practices and the suite of knowledge they are based on, referred to as Traditional Ecological Knowledge (TEK) and traditional land management practices, are becoming more widely recognized as effective tools for counteracting climate change within California (Goode et al. 2018). TEK and traditional land management may serve as great resources to help reconceptualize ecological baselines and the kinds of management strategies effective to help achieve these goals.

There are many historical and community factors that impact the use of TEK today in California. After the initial impacts of the Spanish Mission system, the policies, acts, and decisions by the Bureau of Indian Affairs, the State of California, and the US government continued to systematically impact Native Communities, leading to the high rates of poverty, food insecurity, and poor health conditions, especially related to diet-related diseases, which are issues that continue today (Castillo 1978; Sowerwine et al. 2019a). Many tribal communities have been mounting efforts to reclaim their past, traditional knowledge of native ecology, and culture. Many tribal groups are also working to revitalize their communities through education, outreach, food sovereignty movements, and attempts to reclaim rights to traditional and sacred lands (Milliken et al. 2009; Sowerwine et al. 2019a,b; Wires and LaRose 2019). TEK is intrinsically tied to the health and welfare of California tribal communities and their history. What TEK is known and remembered is not the exact same as it was at European contact. Similarly, it likely changed even between the multiple generations over the thousands of years people have occupied California; Native Californian land management practices and culture changed since humans entered the state based on the archaeological record, and TEK by necessity has likely transformed over time with it. Despite this, much TEK has survived and is still used and practiced to this day.

Traditional land management using TEK has been shown to be a potentially effective tool in conservation efforts and against commonly experienced health problems in Native Communities, including depression, addiction, and diet-related diseases such as diabetes (Goode et al. 2018; Sowerwine et al. 2019a). For example, studies have shown that the prevalence of diabetes in tribal communities is inversely related to access to traditional food resources, meaning that communities that reclaim their traditional dietary practices tend to have lower incidence of diabetes and other metabolic conditions (Sowerwine et al. 2019a). The outcomes of a five-year grant to help the tribes of the Klamath River Basin move toward food sovereignty provide a clear example of these potential impacts but is beyond the scope of this review (for more information, see Sowerwine et al. 2019a). However, an additional potential benefit to such collaborations and initiatives beyond direct impacts to the Native Californian community is the promotion of native species traditionally harvested for food. Initiatives such as these also represent the potential for further multi-agency collaborations between tribal, local, state, and federal organizations that can benefit the environment, community, health outcomes, and equity initiatives for marginalized groups.

Concluding thoughts.—Humans have always had a complex relationship with the environment, where culture can act as either a buffer or catalyst to environmental stressors.

Humans create niches in all environments in which they live, managing the landscape in ways that are often mutually beneficial for humans and wildlife. Thus, biologists are faced with a challenge when it comes to accounting for the thousands of years of accumulated impacts of humans interacting with their environment on species populations, especially for estimating ecological baselines. Archaeological data can help address this dearth of information in California by providing insights into the effects of human niche construction prior to European contact. Furthermore, by understanding the archaeological record, it may be easier to also understand how different human land use strategies impacted habitats and species, and how those relationships changed through time.

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Send any questions to:
Ange Darnell Baker, PhD
Editor-in-Chief, California Fish and Wildlife Journal
California Department of Fish and Wildlife
(916) 376-8671
Angela.Baker@wildlife.ca.gov

Front. A coyote (*Canis latrans*), one of North America's most widespread native species, overlooking the city of San Francisco. Photo credit: ©janetkessler/coyoteyipps.com

Back. A mule deer doe (*Odocoileus hemionus*) with fawn, looking at a trail camera overlooking the City of Los Angeles at night. Photo credit: ©Johanna Turner-Cougar Conservancy

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