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Social Effectiveness and Human-Wildlife Conflict: Linking the Ecological Effectiveness and Social Acceptability of Livestock Protection Tools

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Human-wildlife interactions are embedded within socio-ecological systems (SES), in which animal behavior and human decision-making reciprocally interact. While a growing body of research addresses specific social and ecological elements of human-wildlife interactions, including conflicts, integrating these approaches is essential for identifying practical and effective solutions. Carnivore predation on livestock can threaten human livelihoods, weaken relationships among stakeholders, and precipitate carnivore declines. As carnivores have received greater protection in recent decades, researchers and managers have sought non-lethal tools to reduce predation and promote coexistence between livestock producers and carnivores. For these tools to be successful, they must effectively deter carnivores, and they must also be adopted by producers. Relatively few studies examine the practical and context-specific effectiveness of non-lethal tools, and even fewer simultaneously consider their social acceptability among producers. To address this gap, we suggest that a tool's ecological effectiveness and social acceptability be analyzed concurrently to determine its *social effectiveness*. We thus paired an experimental study of a carnivore predation deterrent called Foxlights® with qualitative interviews of livestock producers in Northern California. We placed camera traps in sheep pastures to measure the response of coyotes (*Canis latrans*) to experimentally deployed Foxlights and interviewed livestock producers before and after the experiment. Our experiment revealed weak evidence for reducing coyote activity with Foxlights, but interviews revealed that the potential adoption of tools had as much to do with their social acceptability and implementation feasibility as with evidence-based measurements of tool effectiveness. Interviewees viewed Foxlights as potentially effective components of husbandry systems, despite the data suggesting otherwise, demonstrating that scientific reductionism may lag behind producer practices of systems-thinking and that isolated demonstrations of a tool's ecological effectiveness do not drive tool adoption. Future empirical tests of non-lethal tools should better consider producers' perspectives and acknowledge that data-based tests of ecological effectiveness alone have a limited place in producer decision-making. Iteratively working with producers can build trust in scientific outputs through the research process itself.

Keywords: human-wildlife conflict, human-wildlife interactions, conservation planning, monitoring and evaluation, human dimensions of wildlife, conservation social science, non-lethal control, socio-ecological system

INTRODUCTION

Human-wildlife conflict (HWC) can drive wildlife declines and threaten human livelihoods. Large carnivores are particularly susceptible to declines due to conflict because their large ranges, carnivorous diets, and adaptability have put them into frequent contact with people (Ripple et al., 2014; Wolf and Ripple, 2017). The loss of these species can in turn transform ecosystems and trigger collapses (Estes et al., 2011). HWC and the coupled human-natural systems in which conflicts occur are driven by a dynamic array of interconnected social and ecological elements, in what is referred to as socio-ecological systems or SES (Berkes and Folke, 2003; Ostrom, 2009; Lischka et al., 2018). For example, while the behavioral and spatial dynamics of carnivores and their livestock prey may be understood through an ecological lens (Wilkinson et al., 2020), the arena in which these species encounter one another is shaped by past and current land and livestock management practices that are selected through separate and complex social, political and economic processes. Conflict poses considerable challenges for those who bear the costs associated with carnivore conservation (Muhly and Musiani, 2009) and is deeply embedded within the value systems and identities of people who have personal and family histories in agricultural production (Widman and Elofsson, 2018). The traditional roles that conflict management has played in agricultural contexts have been profoundly meaningful, and the symbolic threat of carnivores can be as important as economic hardship in dictating the terms of conflict (Skogen et al., 2019). Thus, integrating the disparate elements of HWC and the feedbacks that link them requires transcending the barriers that have traditionally divided social and bio-physical sciences (Dickman, 2010; Redpath et al., 2012).

There has been a push for applied research on tools to mitigate conflict, but much of this research misses the socio-ecological nature of the problem. For example, livestock-carnivore conflict is one of the most pervasive forms of HWC (Inskip and Zimmermann, 2009; Lute et al., 2018) and management strategies in North America have long relied on lethal strategies aiming to reduce carnivore numbers or eradicate them completely (Reynolds and Tapper, 1996; Berger, 2006; Barnes, 2015). These strategies have recently become less viable for a variety of social reasons (Berger, 2006; McManus et al., 2015; Slagle et al., 2017; Lute et al., 2018) and ecological reasons (Bergstrom, 2017; Lennox et al., 2018; Moreira-Arce et al., 2018). As many carnivore populations in the United States are recovering, wildlife managers and livestock producers require new strategies to protect both livestock and carnivores.

Non-lethal livestock protection has become a central focus of a growing body of research dedicated to carnivore conservation. Research suggests that non-lethal strategies may protect livestock as well as or better than lethal strategies, and there has been an effort to understand their effectiveness by ecological metrics (Miller et al., 2016; Treves et al., 2016; Eklund et al., 2017; Moreira-Arce et al., 2018; van Eeden et al., 2018). Perhaps more importantly, many livestock producers believe that non-lethal strategies are only slightly effective at best and seldom long-lasting (Scasta et al., 2017), which has prompted researchers to call for new empirical studies to convince stakeholders of the value of non-lethal approaches. But these calls often assume that the adoption of tools by stakeholders is singularly guided by their access to conclusive science.

Social acceptability is an important dimension of these non-lethal conflict mitigation tools, as the effectiveness of a tool matters little if producers do not use it. While it is possible that empirical demonstrations of effectiveness may lead to greater adoption of non-lethal strategies (Baker et al., 2008), producers' decisions are not usually informed by academic research (Knapp and Fernandez-Gimenez, 2009) and scientific evidence is often contested or dismissed when social conflict is intense (Woodroffe and Redpath, 2015). Despite the growing scientific understanding of the ecological effectiveness of livestock protection tools, it is unclear whether and how this expanding body of literature influences which tools producers use, as the limits of a tool's applications are also driven by attitudes, values, context, and social networks (Wilmer and Fernández-Giménez, 2015; Pooley et al., 2016; Lozano et al., 2019). Broadening the definition of effectiveness to necessarily include the willingness of stakeholders to adopt tools will require a better understanding of how and why livestock producers make husbandry decisions, how knowledge is transferred and evaluated, and what social and ecological elements inform the social acceptability of a tool. Areas where attitudes and scientific data diverge indicate targets for stakeholder engagement and collaboration.

To investigate how the ecological effectiveness and social acceptability of a non-lethal tool interact to inform an integrated metric of *social effectiveness*, we paired an experiment testing the ecological effectiveness of a predation deterrent (Foxlights®; Bexley North, Australia) with livestock producer interviews in Northern California. We conducted qualitative interviews both before and after sharing the scientific results of the non-lethal tool's ecological effectiveness because this can be a powerful way to examine how science is integrated into a producer's decision-making process (Drury et al., 2011; Wutich et al., 2019; Martin, 2020). Foxlights are predation deterrents that flash randomly timed and colored lights in all directions from sundown to sunup to mimic lights that are associated with human presence, and are designed to be used based on line-of-sight. We chose Foxlights because of their reported ecological effectiveness (Ohrens et al., 2019a; Naha et al., 2020) and growing popularity. We evaluated the effects of Foxlights on coyote (*Canis latrans*) activity in a sheep production operation in Northern California, as coyotes pose the most significant predation risk in this geographical context (USDA, 2015).

We then sought to reciprocally combine our ecological examination of Foxlights with our qualitative approach to estimating social acceptability to produce an integrated socio-ecological understanding of tool adoption. In addition to testing whether Foxlights reduced local coyote activity, we aimed to better understand how producers make decisions, the role empirical science plays in that process, and what other socio-ecological factors serve as opportunities and barriers to tool adoption. We also examined whether our iterative integration of stakeholder knowledge improved receptivity to empirical findings and improved the trustworthiness of both the research and researchers. This situation assessment serves multiple goals, as it can be used to inform the monitoring and evaluation component of a planning cycle, provide a new and transdisciplinary approach to tool evaluation, and reveal how stakeholders may respond to tool recommendations. In the following sections, we will draw from various theories in the field to explain how ecological effectiveness and social acceptability can be used to define *social effectiveness*, describe our qualitative and empirical methods, present the results of the interviews and the Foxlights study, and then summarize how the empirical study and the interviewees' perspectives demonstrate the value of a systems-oriented approach to tool evaluation that accounts for social effectiveness.

THEORETICAL FOUNDATIONS OF SOCIAL EFFECTIVENESS

Multiple theoretical perspectives guided our research. We primarily used a socio-ecological systems (SES) approach to evaluate a given tool's ability to mitigate conflict and promote coexistence, acknowledging that human and animal behaviors are informed by both social and ecological dynamics and feedbacks. Thus, we viewed producer-carnivore conflict as an interaction of humans and animals, whose respective attributes and behaviors have co-developed across overlapping spatial and temporal scales. We used the definition presented by Carter and Linnell (2016) to understand coexistence as a "dynamic but sustainable state" that involves adjusting human interactions with wildlife to ensure co-adaptation, suggesting that coexistence with wildlife requires more intention than merely existing in the same place at the same time. Just as Lischka et al. (2018) accounted for the bidirectional impacts of social and ecological processes on black bear conflict with homeowners, we too acknowledged the individual agency of both producers and coyotes as well as wide-ranging external influences on their behavior. For example, coyote presence in Northern California is impacted by ecosystem characteristics, such as topography and prey abundance, as well as by societal drivers that include tolerance for coyotes (Bruskotter and Wilson, 2014) and patterns of human development. This SES approach thus highlights the need to understand both the social and ecological factors that contribute to conflict and, most importantly, conflict-mitigation.

We propose the term *social effectiveness* that incorporates both ecological effectiveness and social acceptability. An examination of a tool's social effectiveness will fill multiple lacunae in the field of HWC. Currently, not enough is known about which tools are ecologically effective, even less is known about tools' social acceptability, and the field is lacking work that addresses both of these questions simultaneously (Hartel et al., 2019). In our study, we defined ecological effectiveness as the ability of Foxlights to deter coyotes from pastures. We defined social acceptability following Shindler and Brunson (2004) as an ever-evolving process that helps determine the adoption of any particular policy, program, or tool. Social acceptability is not an active area of research within HWC, but several theories suggest its potential importance to this field and point to the need for empirical research on the topic. These theories include hazard acceptance models, human dimensions of wildlife, taskscapes, and diffusion theory, among others. Key components of social acceptability identified both in our research and others include social trust, values and attitudes, context and systems, information transfer, and the research process itself. Here we define these key components as they relate to our study.

Social Trust

Social trust is a major, if not the major, component of social acceptability. Given that HWC does not always involve human conflicts with wildlife but can also entail conflicts between humans over wildlife conservation issues (Redpath et al., 2015; Slagle and Bruskotter, 2019), it follows that social trust among stakeholders can override all factors when it comes to determining the social acceptability of a proposed solution (Shindler and Brunson, 2004). Social trust is defined as a decision-making heuristic that involves conferring some responsibility to an outside entity for things out of one's control, and can be used to examine perceptions of risk and acceptance of new technology (Siegrist, 2000; Siegrist et al., 2000). It is an adaptive process that takes time, requires multiple opportunities for interaction, and is linked with knowledge, honesty, and care (Peters et al., 1997). Social trust is a primary component of the hazard-acceptance model, a psychological model that claims that tolerance for large carnivores is informed by an array of factors including social trust, affect for species, risk perceptions, and tradeoffs (Bruskotter and Wilson, 2014; Slagle and Bruskotter, 2019). In their definition of social acceptability, Shindler and Brunson (2004) identify many of the elements of the hazard acceptance model without naming the term. Given the role of social trust in determining individuals' willingness to rely on external decision-makers, it follows that trust for the researchers studying a particular tool could lead to lower perceived risk in adopting the tool. To build social trust, Bruskotter and Wilson (2014) recommend highlighting shared fundamental values and goals, and Shindler and Brunson (2004) emphasize the importance of cumulative interactions over time. Social trust is especially pertinent to our study, as the social acceptability of a tool is ultimately individually determined (though informed by broader cultural and ecological contexts), and we forged trust with the individual producers over the course of iterative interviews.

Attitudes and Values

Social acceptability is also conditioned by attitudes and values. Here we draw from theories in the field of human dimensions of wildlife (HDW). In particular, we build on research that considers the roles of attitudes and values in informing why humans behave the way they do with regard to wildlife, what human behaviors lead to conflicts, and how human behavior might be influenced to minimize conflict (Manfredo et al., 1995; Decker et al., 2012; Dietsch et al., 2019; Hiroyasu et al., 2019). Attitudes are favorable or unfavorable dispositions toward an action. For example, a positive attitude toward carnivores may explain behaviors like reluctance to employ lethal means of carnivore control. Attitudes are in turn guided by values, which are fundamental, consistent belief systems that transcend specific situations. For example, one's positive attitude toward carnivores may be based on values of mutualism, which is a belief system associated with egalitarian views of wildlife and a conviction that human activity should be limited for the sake of wildlife protection (Manfredo et al., 2017). Attitudes and values are unique to individuals and inform their identities, but values also exist along a continuum and can reflect broader shifts among groups of people. An example is the Western post-WWII movement toward mutualist values from more traditional domination values, which are linked to a belief that wildlife exist for human use. This value shift has resulted in a recent backlash among those with traditional wildlife values, often out of a desire to protect cultural heritage. Manfredo et al. (2017) revealed through a 19-state survey that in states like California that tend toward mutualist values, the potential for social conflict over wildlife issues with people who have domination values was much higher. It follows that carnivores can become emblematic of greater change as their presence becomes further mired within contested values.

In considering social acceptability, we therefore also draw from theories that describe the symbolic roles carnivores play in determining attitudes and values. In particular, our research builds on the theory of "taskscapes," which involves looking at how a landscape is understood by the histories and identities connected to the work and play people undertake in it (Ingold, 2000; Skogen et al., 2019). People are generally more concerned by taskscape changes, or changes to how a landscape is used, than by physical landscape changes. Carnivores can become symbols of greater taskscape change if the changes that bring carnivores are perceived as being imposed by threatening external forces, meaning that anti-carnivore attitudes can develop independently of material costs. On the other hand, positive attitudes toward the changes that bring carnivores may foster tolerance as long as material damage is not extensive. Approaches like non-lethal tools aim to concurrently help producers achieve livelihood goals *and* promote carnivore conservation. Thus, the attitudes producers hold toward these tools may be linked to their attitudes toward carnivores and all that carnivores symbolize within a taskscape.

Context and Systems

Social acceptability can be specific to a given context, as a solution or tool that is appropriate in one system may not be appropriate in another (Shindler and Brunson, 2004). For example, the heterogeneity of ranch characteristics and ecoregions in combination with individual producer attributes may mean that no single solution can satisfy the diverse needs of varied ranch operations (Roche et al., 2015). A systems approach can thus help account for the complexity of a producer's decision-making process by acknowledging that social acceptability does not exist in a vacuum; it is instead in relation to what the alternative solutions are perceived to be within a given context. For example, producers operating on privately-leased land often have a different set of alternatives than those on publicly-leased land. Brunson (1996) defined social acceptability as a "condition that results from a judgmental process by which individuals (1) compare the perceived reality with its known alternatives, and (2) decide whether the real condition is superior, or sufficiently similar, to the most favorable alternative condition." Alternatives are difficult to articulate simply, although this is often what is done when alternatives are presented to producers. For example, non-lethal methods and lethal methods are often presented as alternatives to each other, even though they can be employed simultaneously. This renders social acceptability a dynamic and potentially "wicked" process that changes with available alternatives (Rittel and Webber, 1973; Whyte and Thompson, 2012; Mertens, 2015). What may have been acceptable in the past can become unacceptable in the future. This dynamism further underscores the need for an iterative process of stakeholder outreach in order to continue to assess social acceptability as both context and systems evolve.

Information Transfer and Research Process

The way that information is transferred as well as the research process itself also informs social acceptability. Studies have found that producers primarily get their information via word-of-mouth, especially from neighbors and other producers, as opposed to technical sources (Rowan et al., 1994; Kachergis et al., 2013; Roche et al., 2015). For example, diffusion theory presents producers as rational actors who utilize social networks to make decisions. This theory supports the finding that the adoption of new technologies generally begins with opinion leaders, who are producers that are well-connected within knowledge networks (Lubell et al., 2013). These opinion leaders then pass on new technologies to others in their networks, or new technologies are passed down through ranch family generations. A tool's social acceptability can thus be influenced by the way a producer learns about the tool and who they learn this information from. Furthermore, the way in which people are incorporated into a decision-making process can influence their attitudes and judgements (Shindler and Brunson, 2004). Thus, transdisciplinary approaches that emphasize producer involvement may contribute to the social acceptability of research findings, and such approaches have been called for by previous researchers (Hartel et al., 2019). Disciplinary or interdisciplinary approaches on their own are not always flexible enough to be able to address real-world problems because they do not incorporate non-academic actors. Conversely, transdisciplinary approaches aim to identify solutions via a process of cocreation by incorporating differing values and perspectives that better reflect the de facto decision-making process. These collaborative efforts enable researchers to span multiple social networks and coproduce knowledge with livestock producers who can contribute their own diverse epistemic backgrounds.

Ecological Effectiveness

We based our metrics of ecological effectiveness on several reviews that systemically evaluated experiments on lethal and nonlethal livestock protection methods (Miller et al., 2016; Treves et al., 2016; Eklund et al., 2017; van Eeden et al., 2018). These reviews sought to determine which interventions work best, and generally defined ecological effectiveness as the change in livestock loss or carnivore presence in pastures before and after techniques were applied or between control and treatment groups. None of the reviews were able to make any definitive claims and determine "what works" due to a lack of robust studies. Given that the field of HWC lacks a consistent standard for evidence of ecological effectiveness, the authors of these reviews have called for future examinations of ecological effectiveness to satisfy a "gold standard" of scientific rigor that pays special attention to controls, randomization, and replication.

To achieve the gold standard for scientific inference, evaluations of a tool's ecological effectiveness should aim to avoid bias by randomly assigning control and treatment groups and consistently implementing interventions across all groups. An evidence-based, case-control study should thus ideally involve a comparison between a randomly selected treatment livestock herd that is exposed to an intervention and a control livestock herd that is not exposed. While the reviews acknowledge that a tool's effectiveness is context dependent and subject to complex ecological and social confounds, they nevertheless urge ecological evaluations to use measurements of effectiveness that are as controlled and unbiased as possible. All reviews therefore excluded correlational studies or looked at them only as a supplement to their analysis. van Eeden et al. (2018) also acknowledged that input from multiple stakeholders, including scientists and livestock producers, are needed to guide the empirical tests of tools and contribute to the research process.

Like these studies, we too defined ecological effectiveness as a change in carnivore behavior (i.e., detections) within an experimental framework. The relationship between detections and predation is complex. In another study of Foxlight effectiveness, Naha et al. (2020) found that Foxlights led to a significant decline in livestock predation but no difference in leopard visitation between experimental and control sites. Thus, deterrents may diminish a carnivore's willingness to expend the energy and assume the risk associated with predation without altering visitation rates (Wilkinson et al., 2020). Nevertheless, it is important to look at detections in addition to predation events because the harassment and stress associated with mere carnivore presence can affect the health of livestock herds (Ramler et al., 2014).

Taken together, ecological effectiveness and social acceptability contribute to the social effectiveness of a given tool and determine adoption. When analyzing Foxlights, we acknowledged that the social effectiveness of a tool varies across individuals, systems, and timescales. We use this study as an example of how taking these considerations into account can improve future evaluations of tools like Foxlights.

METHODS

We organized this methods section to reflect the approaches we took to analyze both social acceptability and ecological effectiveness. We first discuss one, then the other. We took our pre-understanding into account before beginning this process and recognized that our analysis of the data would mirror our individual backgrounds and contextual knowledge. Our group of coauthors have a uniquely interdisciplinary background steeped in social and ecological science, and we have conducted research at the study site (HREC) in some form since 2014. This granted us familiarity with the California rangeland system and with the local dynamics of conflict throughout interviews. We were always transparent about our backgrounds with producers and made it clear that our goal was to thoroughly integrate producers into the research process.

Producer Attitudes

Interviews

We conducted semi-structured interviews with 11 sheep and cattle producers in Northern California before and after completing our empirical evaluation of Foxlights (see section Predation Deterrent Experiment). Given our qualitative approach, our interviewee pool was small and the results were not intended to have universal applicability or be generalized statistically. These livestock producers operated in Mendocino, Alameda, Sonoma, San Mateo, and Contra Costa counties (all of which are geographically, climatically, and culturally similar), while the Foxlight experiment took place at the Hopland Research and Extension Center (HREC) in Mendocino County. This region has a history of sheep production, with a decline in recent decades. Many producers attribute the decline to an increase in coyote predation (Larson et al., 2016), while other sources attribute it to broader economic change (Berger, 2006).

We began by interviewing HREC producers who managed the sheep flocks that were involved in the Foxlight experiment. These producers had a professional stake in HREC's sheep management and some input on the sheep program but no direct stake in the finances of the program. Other interviewees were then identified via a network sampling technique, which involved contacting future interviewees from recommendations of past interviewees (Noy, 2008). The only requirements were that the interviewees identified as livestock producers and were willing to be interviewed. Of the 11 interviewees, three were employed at HREC, three operated on privately leased lands, three on publicly leased lands, and two on a mixture of public and private leases. Livestock herd size ranged from one producer who was responsible for 70 sheep to another producer who ran 600 mother cows. All 11 producers had experienced livestock loss to coyotes, ranging from one producer who stated that they lose 25% of their calf crop to coyotes every year to another producer who only had one experience with coyote predation.

Each interview lasted from 30 min to 2 h. We started with a set of predetermined open-ended questions (**Supplementary Material**) and posed additional questions as the conversations evolved. Interviews covered tool use, information sources, identity and landscape change, definitions of coexistence, affect toward carnivores, and the material and emotional costs associated with livestock loss. All interviews were recorded with permission from the interviewees and transcribed for analyses. The study protocol was reviewed and approved by the University of California, Berkeley Committee for Protection of Human Subjects (CPHS Protocol Number: 2019-02-11801).

After the Foxlight experiment analyses were completed, we contacted the 11 previously interviewed producers to investigate whether empirical findings would change their attitudes toward Foxlights. This second round of interviews involved briefing interviewees on the study results without firm claims on the conclusions. We began by explaining the research and our desire to use a SES approach to evaluate a livestock protection tool that incorporated producer perspectives. We then presented the Foxlight experiment methods and results with special attention to the lack of a strong signal in the data. We made it clear that our study was not able to make any definitive claims about how Foxlight presence interacted with predation due to limited data. Interviewees asked clarifying questions throughout the presentation and sometimes proffered their own interpretation of the empirical results. To ensure continuity, the same authors who conducted the interviews also transcribed and analyzed interview transcripts.

Interview Analyses

We employed a qualitative content analysis method known as *manifest analysis* (Elo and Kyngäs, 2008; Bengtsson, 2016; Carlson, 2018; Okumah et al., 2020; Pimid et al., 2020) to examine interview transcripts. This method emphasizes staying close to the original data and is unique because it has both quantitative and qualitative methodology.

Each transcript was analyzed through hand coding (**Figure 1**). The first stage was *decontextualization*, where we began with a precursory reading of the transcripts, followed by a second readthrough where certain quotes were selected and color-coded by theme (Bengtsson, 2016). Examples of themes included "definitions of coexistence" or "opinions toward science. "Selected quotes were paraphrased into meaning units by cutting crutch words or redundant phrases while staying true to the text. After this, meaning units were assigned codes that we created throughout the analysis process. We used *inductive content analysis* to create codes based on abstraction from the specific to the more general while remaining as text-driven as possible (Elo and Kyngäs, 2008; Graneheim et al., 2017). We relied on *open coding*, a unique component of inductive content analysis, to detect patterns and freely generate categories as we read and re-read transcripts. This allowed us to imbue the original text with agency but also meant that codes evolved as the study progressed. To avoid obscuring the meaning of these codes, the coding process was repeated until codes stopped evolving, which often involved collapsing similar but more specifically worded codes into broader and more generalizable versions.

After assigning codes, we began the "compilation stage," where we combined a quantitative and qualitative approach to detect patterns and extract meaning from the text. We counted the number of times a given code appeared across all interviews and presented the final number in the tables. Even though a single code could be present multiple times within a single transcript, codes were only counted once per interview. Then we progressed to the writing process, where we used manifest analysis to gather meaning from the text, which is what is presented in the results. Manifest analysis involves describing *what* the informants say, as opposed to trying to find hidden meanings or subtext. Thus, we referred to the original text as much as possible. Together, these quantitative and qualitative approaches helped us conceptualize social effectiveness by allowing us to assess how the various elements of social acceptability interacted with the demonstrated ecological effectiveness of Foxlights.

Predation Deterrent Experiment

Study Site

The Foxlight experiment took place at the Hopland Research and Extension Center (HREC) in Mendocino County. HREC is a 5,358-acre sheep production and education facility in the Mayacamas Mountains. University of California acquired the study site, a former sheep ranch, in 1951, and has been managing sheep on the site ever since. Native carnivores at the site include coyotes, black bears (*Ursus americanus*), mountain lions (*Puma concolor*), and bobcats (*Lynx rufus*). Coyote predation is the main issue for sheep at HREC (Scrivner et al., 1985; Neale et al., 1998; McInturff et al., 2020), with ewe and lamb loss ranging from 1 to 3% a year since 2015. Sheep at HREC are generally moved between fenced pastures every 2 to 6 weeks. Sheep flocks are most vulnerable to predation during lambing season, which occurred twice during this study from November to March. At the start of the study, the operation supported 450–500 ewes over 32 pastures, but was reduced to 135 ewes in June 2019 due to budget and staffing constraints.

Study Design

We tested the behavioral response of coyotes to Foxlights from October 2018 to January 2020 using an experimental design. We compared coyote detections between treatment sites, or camera traps in areas that were in the line-of-sight of a Foxlight (henceforth active Foxlight sites), and control sites, or camera traps set in areas without Foxlights (henceforth inactive Foxlights sites). We selected six pastures based on the recommendations of HREC producers, prioritizing areas that were commonly occupied by sheep flocks and/or reportedly frequented by coyotes. Five of the six pastures were used for sheep grazing at some point during this study. Each pasture contained paired camera trap sites (an active Foxlight site and inactive Foxlight site), yielding 12 total camera trap sites (**Figure 2**). Camera

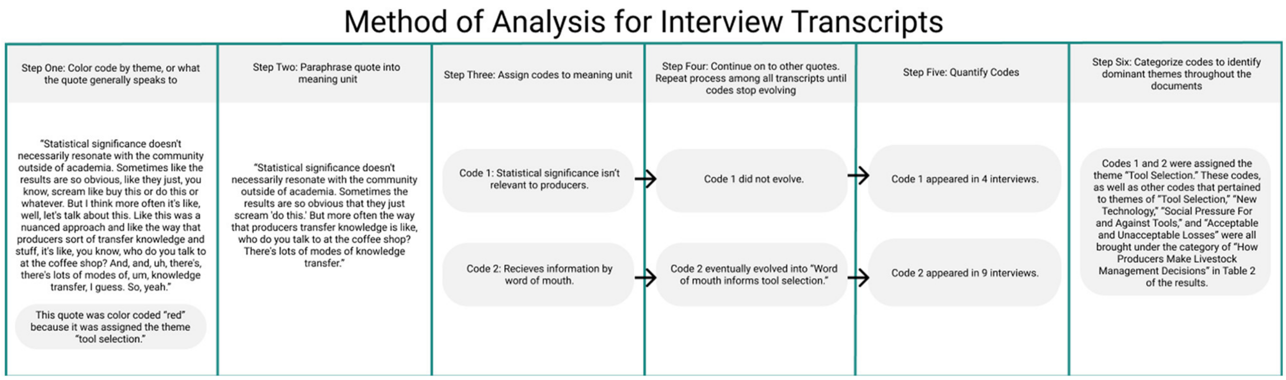

FIGURE 1 | Method of analysis for interview transcripts. This figure demonstrates how we created meaning units, derived codes from meaning units, and then quantified codes to be presented in tables.

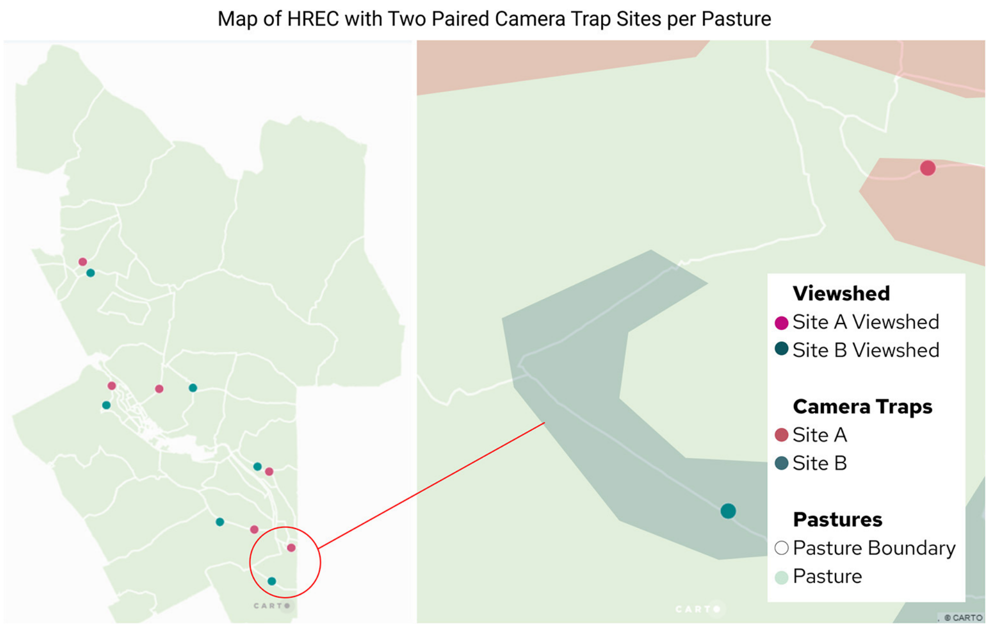

FIGURE 2 | Map of HREC with two paired camera trap sites per pasture. Each pasture's Foxlight was alternated between two sites every 5 weeks, and a camera trap was placed at each site to continuously monitor coyote activity throughout the phase. Each phase was composed of two 5 week periods (such that within a given phase, each camera trap site had 5 weeks with a Foxlight, and 5 weeks without a Foxlight). In the figure, "viewshed" represents the areas of the pasture that were in the line-of-sight of the Foxlight when it was active. It was not possible to view a Foxlight in one site from any other. Image produced on Carto.

traps were placed near coyote sign (i.e., game trails, dig holes, fence brakes) to maximize detections (Way and Eatough, 2006; DeVault et al., 2008). Camera traps (Bushnell Trophy Cam) were programmed to take bursts of two pictures at 10 s intervals when triggered and set with a normal sensor level.

Throughout the study, one Foxlight was always operational in each of the six pastures. We ensured that Foxlights were not visible from any other camera trap site, even when deployed in the same pasture. Foxlights were placed in prominent areas, such as atop of a knoll, in the center of narrow pastures, or atop of fences in larger pastures, and within 100 m from the camera trap. Within each pasture, we moved the Foxlight between the active and inactive site every 5 weeks. We defined a study "phase" as a 10-week period during which each Foxlight was active for 5 weeks and inactive for 5 weeks at a given camera trap site. There were a total of 4.5 phases during our study. Due to camera trap malfunctions, some cameras had incomplete phases whereas other cameras had longer phases. We corrected for these differences in our analysis.

Analytical Methods

We used Generalized Linear Mixed Models (GLMMs) to analyze the effects of Foxlights on coyote activity patterns. We determined the number of coyote camera trap detections during each 5 week active or inactive Foxlight period and used this measure as the dependent variable in all models. We counted camera trap photos that occurred within 15 min of another as one independent detection, as inspection of the raw data suggested that this interval captured unique coyote groups while minimizing pseudo replication (following Šver et al., 2016; Dorning and Harris, 2019).

We used a negative binomial model to account for overdispersion of the count data and included the number of operational days in each active and inactive Foxlight period as an offset in the models to account for differences in sampling effort across camera phases. The covariates we considered to influence coyote activity were Foxlight status (binary variable), sheep presence as a potential coyote attractant (binary variable), phase in order to measure habituation (1–4), and ruggedness at a resolution of 2,500 m^2 around each individual camera trap because it was assumed to have an impact on Foxlight visibility. To ensure that correlated covariates were not confounding the results of our analyses, we tested all covariates in the top model for collinearity and confirmed that variance inflation factors (VIF) < 4 (this was the case for all models). We scaled ruggedness prior to modeling (mean of 0 and standard deviation of 1). We included camera as a random effect in all models, which controls for habitat variables. We selected the best model based on AIC (Burnham and Anderson, 2002).

We also examined whether Foxlights affected coyote diel activity patterns. To account for the circularity of the data and for seasonal differences in sunset and sunrise time, we scaled all times to radians so that $\pi/2$ corresponded to sunrise and $3\pi/2$ to sunset. We used kernel density estimation to model diel activity patterns for coyotes during periods with and without Foxlights (Ridout and Linkie, 2009). We used Watson's two-sample test of homogeneity to test for differences in daily activity patterns in areas with and without Foxlights, using the circular package in R (Agostinelli and Lund, 2017).

RESULTS

Results are organized based on social acceptability (sections Producer Attitudes Toward Foxlights Prior to Seeing Results and How Producers Make Livestock Management Decisions), ecological effectiveness (section Effect of Foxlights on Coyote Activity), and social effectiveness (sections How Producers Interpreted the Results and Attitudes Toward Science and Our Methods).

Producer Attitudes Toward Foxlights Prior to Seeing Results

Ten of the eleven interviewees utilized non-lethal deterrents or strategies. These strategies included, in order from most frequently to least frequently cited: guardian animals, human presence, electric fencing, Foxlights, night penning, strategic pasture selection, tighter calving/lambing season, E-collars, solar motion lights, fladry, and radios.

Most interviewees were either willing to use Foxlights or already used them (**Table 1**). One of these interviewees stated,

TABLE 1 | Producer attitudes toward Foxlights prior to seeing results of the experiment.

Theme	Code	Interviewees
Attitude toward Foxlights	No prior knowledge of Foxlights	4
	Willing to adopt Foxlights	4
	Already uses Foxlights	4
	Not willing to adopt Foxlights	3
Concerns about Foxlights	Lethal means are the best strategy against predation	4
	Concerns about habituation	3
	Concerns about lack of feasibility on public lands	3
	Concerns about cost	2
	Concerns about ruggedness and terrain	1

Each quote, or meaning unit, was assigned a code that corresponded with a theme. Meaning units could have multiple codes. The codes presented here are derived from interview transcriptions of 11 interviews. Interviewees are color-coded by percentage–a dark box color means more interviewees had meaning units in their interviews that were assigned that code than a light box color.

"Yeah, I would [adopt Foxlights]. I would do it if somebody gives me a new idea on how to deter predators from sheep. I would use it in a second and then watch probably for a season to see if it was working and then if it worked out, keep doing it. If it didn't, I would look for something else." In contrast, interviewees that were unwilling to try Foxlights either had concerns about the feasibility of deploying deterrents on public land, had too few issues with predation to warrant investing in deterrents, or did not believe in the effectiveness of non-lethal deterrents. To this latter end, one interviewee stated, "I know a lot people don't like to hear this, particularly in the academia world, but the only effective way to control, particularly the coyotes, is lethally. I'm familiar with the system [Foxlights] that you mentioned, but they're just not feasible."

How Producers Make Livestock Management Decisions

According to both rounds of interviews, interviewees relied on multiple outlets and factors to make ranch management decisions (**Table 2**), with word-of-mouth serving as the most prominent information source. Tool adoption, as one interviewee described it, "depends on who recommends that tool." Producers who identified word-of-mouth as an influence on their decision-making described various kinds of relationships, listed here from order of most frequently to least frequently cited: other producers, neighbors, landowners, suppliers, friends, and researchers. When producers did get information from researchers, the researchers often either worked for their land management agency or had worked with a producer they personally knew. Producers did not commonly rely on academic research papers to make decisions, as one interviewee stated, "I'm certainly not combing through research journals as a

TABLE 2 | How producers make livestock management decisions.

Subject	Code	Interviewees
Tool selection	Word of mouth informs tool selection	9
	Other producers inform tool selection	7
	Tradeshows, workshops, and seminars inform tool selection	6
	Agricultural websites, newsletters, and catalogs inform tool selection	5
	Landowner informs tool selection	4
	Personal experience informs tool selection	4
	Scientific papers inform tool selection	4
	Suppliers/manufacturers inform tool selection	4
	Wildlife organizations inform tool selection	3
	Does not seek information when it comes to selecting tools	2
New technology	Livestock producers need new technology	6
	Livestock producers do not necessarily need new technology	2
Social pressure for and against tools	Stated personal preference for either lethal or non-lethal tools	9
	There is social pressure from the public against lethal tools	9
	There is social pressure from other producers to use lethal tools	5
	There is social pressure from other producers against lethal tools	2
	There is social pressure from other producers to use non-lethal tools	2
	There is social pressure from other producers against non-lethal tools	1
Acceptable and unacceptable losses	There is a such thing as an acceptable level of loss to carnivores	9
	There is no such thing as an acceptable loss to carnivores	1
	Not all coyotes pose risks, only certain "problem" coyotes do	9
	Carnivores can display acceptable or unacceptable behavior	7

Each quote, or meaning unit, was assigned a code that corresponded with a theme. Meaning units could have multiple codes. The codes presented here are derived from interview transcriptions of 11 interviews. Interviewees are color-coded by percentage–a dark box color means more interviewees had meaning units in their interviews that were assigned that code than a light box color.

producer." Five producers also mentioned that their access to tools, including lethal strategies, was limited by the sites or conditions of where and with whom they worked.

Interviewees cited social pressure and personal preference as influencing tool selection. For example, one interviewee stated that social pressure "can go both ways. There's social pressure to adopt non-lethal and there's social pressure from the other side to adopt lethal. Because any coyote I take out isn't predating my neighbors. So when you have a core group of say four or five ranches that are all bordering each other, they're going to put pressure, you know, I'm doing my part to get rid of the coyotes, what are you doing? But definitely there's more pressure to do the non-lethal stuff than there is anything else." Another interviewee stated, "I would say, lethal control aside, I don't think there is any public pressure on one tool vs. another. It's like, if something worked for you use it. If it doesn't work for you, don't use it. You know, try it out, let me know how it works."

Several interviewees discussed their approach to deciding between non-lethal and lethal strategies for managing conflict, displaying varying thresholds of tolerance for livestock loss or carnivore behaviors before implementing lethal strategies. For example, one interviewee stated, "I find [coyotes] really interesting and exciting, but there's this threshold that's crossed if they're inflicting damage to my animals." Examples of unacceptable livestock loss included: more than 1% of cattle a year (depending on how many preventative measures were in place), more than 2% of ewes, more than one or two ewes, losing multiple animals in a short period of time, or if all livestock losses occurred within one herd. Unacceptable behaviors included: when carnivores were particularly wasteful (i.e., mass predation events or if carnivores only ate a small part of an animal), when carnivores "packed up" into large numbers, when carnivores demonstrated habituated behavior (i.e., lack of fear of humans), when carnivores predated healthy animals as opposed to weaker ones, or when carnivores entered atypical areas.

Effect of Foxlights on Coyote Activity

Our experimental evaluation of Foxlights at the Hopland Research and Extension Center (HREC) recorded a total of 305 coyote detections over 4,915 camera trap-nights. The mean number of coyote detections per active Foxlight period at a given camera (5 weeks) was 2.1 (SD +/−3.15; **Figure 3**). For inactive Foxlight periods, the mean was 2.45 (SD +/−3.1; **Figure 3**).

None of the models of coyote activity that we tested improved upon the null model (**Table 3**), though four models were within 2 delta AIC of the null model and one model had the same AIC as the null model (Model 1). Therefore, they may all be considered top models. Model 1, which included Foxlight status (coefficient estimate = −0.12, SD = 0.22), ruggedness (estimate = −0.61, SD = 0.26), and an interaction between the two (estimate = 0.25, SD = 0.26), suggested that ruggedness reduced the impact of Foxlights on coyote activity. Model 4, which only

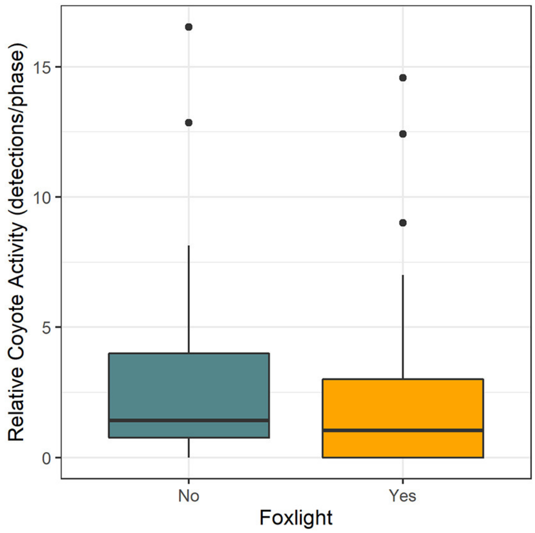

FIGURE 3 | Relative coyote activity by Foxlight status. Relative coyote activity represents the number of coyote detections in a given 5 week period.

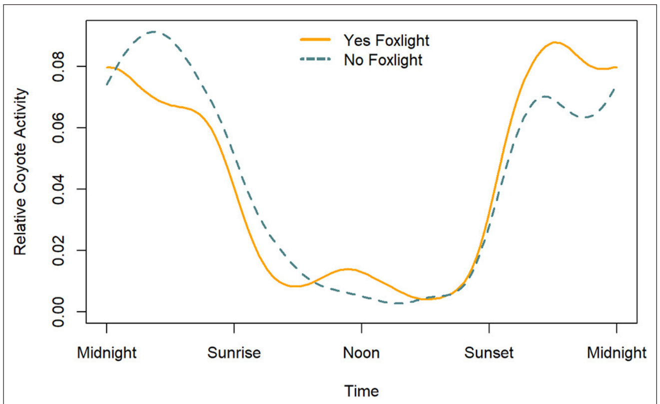

FIGURE 4 | Relative coyote activity by time of day. The lines represent the density of 24-h coyote diel activity across all periods with active Foxlights and inactive Foxlights.

TABLE 3 | Model selection for coyote detections across Foxlight phases.

Model ID	Covariates	AIC	ΔAIC
Null	**Null: (1|Camera)**	**424.4**	**0**
Model 1	**Model 1: Foxlight * Ruggedness at 2,500 m^2**	**424.4**	**0**
Model 2	*Sheep*	*424.7*	*0.3*
Model 3	*Phase*	*424.8*	*0.4*
Model 4	*Foxlight*	*425.6*	*1.2*
Model 5	*Foxlight + Sheep + Phase*	*426.4*	*2*
Model 6	Foxlight * Sheep	427.5	3.1
Model 7	Foxlight * Phase	427.7	3.2

Table includes all candidate models, including the null model (intercept and random effect only). The best models (lowest AIC) are bolded. Other candidate models within 2 AIC of the best model are italicized. AIC, Akaike Information Criterion. ΔAIC, difference between model AIC and the AIC of the best model.

included Foxlight status as a predictor, suggested that coyote activity decreased when Foxlights were active (Model 4, estimate = −0.20, SD = 0.22). Other top models suggested that coyote activity increased when sheep were present (Model 2, Model 5), and generally decreased with phase (Model 3, Model 5). There was no evidence to suggest that an interaction between Foxlight status and sheep (Model 6) or Foxlight status and phase (Model 7) influenced coyote detections.

There was no difference in diel activity patterns of coyotes at sites with active Foxlights than at sites without active Foxlights (**Figure 4**, Watson's $U^2 = 0.098$, $p > 0.10$).

Coyotes predated 14 sheep during the span of the study on the nearly 5,400 acres of HREC property. Of these 14 deaths, 6 occurred in pastures that were in our study area, and none occurred in the line-of-sight of an active Foxlight.

How Producers Interpreted the Results

Nine of the original eleven interviewees agreed to a second interview (**Table 4**). After being briefed on results of the Foxlight field study, eight of the nine interviewees either stated that Foxlights were effective or that Foxlights had the potential to be effective. For example, one interviewee stated, "It seems like Foxlights are not as effective as we would like them to be. But most of us know that this is not the only tool and anything that helps even a little bit is probably worth trying." Another interviewee stated that, "There's a good chance that with more precise, timely usage that [Foxlights] would be more effective. My feeling is that I'd probably be better at using them than they were used. So [your study] leads me to err on the side of using them, which I ultimately think what applied science is about." Interviewees that were already willing to adopt Foxlights or were already using Foxlights in the first round of interviews retained their stance on the ecological effectiveness of Foxlights after viewing our results. However, two of the three interviewees that had been unwilling to adopt Foxlights stated that Foxlights had the potential to be ecologically effective after viewing the results. The third interviewee retained their stance that Foxlights are ecologically ineffective.

When asked what our study may have overlooked, eight of the nine interviewees emphasized taking the natural histories of coyotes into account, timing the use of deterrents with seasonal changes in their activity and behavior, and identifying what other landscape variables may or may not push coyotes to undertake the risks associated with sheep predation (e.g., two interviewees postulated that if lethal take had recently fractured coyote social dynamics, coyotes on the site may have been less risk averse). Recommendations included looking at how coyotes change their behaviors based on: time of year, drought conditions, prey populations, pupping, the activities of neighboring livestock operations, and calving/lambing season. Interviewees emphasized holism, system dynamics, and context. For example, one interviewee stated, "Because of the system dynamics, even if only one out of ten coyotes is afraid of a

TABLE 4 | How producers interpreted the results.

Theme	Code	Interviewees
Foxlight efficacy	Foxlights are effective	4
	Foxlights have the potential to be effective if used differently than in this study	4
	Foxlights are not effective	1
Recommendations for foxlight use	Foxlights would be more effective if used in flatter areas	4
	Foxlights should be studied across multiple operations	3
	Foxlights would be more effective if used in more targeted areas	3
	Foxlight placement should be more randomized than it was in this study	3
	Only use Foxlights during lambing or calving season	3
	Use more Foxlights than what were used in this study	2
Recommendations for research	Environmental factors and coyote behaviors should be incorporated into analysis	9
	Cares more about predation events than coyote detections	5
	There is value in analyzing multiple deterrents at once	5
	There is value in analyzing individual deterrents	4
	This research did not overlook anything.	3

Each quote, or meaning unit, was assigned a code that corresponded with a theme. Meaning units could have multiple codes. The codes presented here are derived from interview transcriptions of 9 interviews. Interviewees are color-coded by percentage–a dark box color means more interviewees had meaning units in their interviews that were assigned that code than a light box color.

Foxlight, that means I get one more lamb a year, maybe, and I've paid for my Foxlight, right?" Another interviewee stated, "On a flat field with no terrain to speak of, maybe [Foxlights] would work. But I'm not unconvinced to buy one. I would still try it. Context in general [is my biggest consideration]. There are so many other variables that you can't control for in research and especially in rangelands. All of [the other factors] are things that still make me want to try a Foxlight." A third interviewee stated that Foxlights are "not that effective. In the context that they were tested in. I still feel like they would be effective in a different context, but it makes sense to me why it wouldn't have been that effective in the broad acreage."

Five of the nine interviewees stated there is value in analyzing multiple deterrents at once. For example, one interviewee stated that they would "love to see a chart that's like—what are the most effective tools in combination." Another interviewee stated that if the goal is to "try to prevent coyote predation of sheep and it doesn't matter what tools you use, then you would maybe do a study on a combination of tools [to see] what works best." Other interviewees warned against too much complexity. To this end, one interviewee stated that "sometimes holism and complexity can be an excuse to arrive at a point where you kind of give up on actual decision-making."

Attitudes Toward Science and Our Methods

Interviewees expressed opinions toward science in the context of rangeland management throughout the course of the two interviews (**Table 5**). Half of the interviewees stated that science can be biased, three stated that personally trusting or knowing the researchers is what makes science significant to them, and only one interviewee stated that producers are the intended audience of livestock-carnivore conflict research. Otherwise, interviewees tended to identify "other researchers," "policymakers," or "customers" as the target audience of research. Five interviewees stated that they trusted the validity of this study after viewing the empirical results, citing its lack of bias, its systems-oriented approach to methods and analysis, its inconclusive results, its accessible explanation of the results in "layman's terms," and its incorporation of producer perspectives. For example, one interviewee stated, "There are types of research that seem really aware where you interview producers, like this is great that you're interviewing producers and I think that really feels valuable to me [because it] makes it seem like this is actually applicable." As a demonstration of perceptions of bias, another interviewee stated, "I judge research by the people that do it, and there are very few people I trust doing livestock research. [This study represents] a group I got to know and I trust them. They had no personal agenda involved, and that's key." As for perceptions of exclusion, another interviewee stated, "Like as a producer, [we] would look at [scientific papers] and say, this is specifically written so I cannot understand it. You know, to make it exclusionary or whatever. So maybe that's why producers wouldn't read that. Not because they're not interested, but because it's just too academic in a different perspective, almost in a different language. I think if a lot of these results were put out in a more usable, friendly format to people, they would for sure pay attention."

DISCUSSION

Our research demonstrated that an integrated assessment of social effectiveness that combines ecological effectiveness and social acceptability adds critical new dimensions to our understanding of the broader capabilities and adoption of non-lethal livestock protection tools.

Our empirical results provided weak evidence that Foxlights affect coyote activity, but most livestock producers we

TABLE 5 | Attitudes toward science and our methods.

Subject	Code	Interviewees
Attitudes toward science	Referred to at least one research paper or study when discussing carnivores	6
	Science can be biased	5
	Trusts the validity of this study despite perceptions of bias in science	5
What makes research significant	Research is significant when it aids with decision making	5
	Statistical significance is not relevant to producers	4
	Statistical significance is relevant to producers	3
	Research is significant when researchers are trusted	3
	Research is significant when it uses real-life ranching operations	3
	Research is significant when it is presented in a way that is accessible to producers	2
Attitudes toward our study	Trusts our research because they agree with and understood our methods	5
	Trusts our research because we did not have a personal agenda	4
	Trusts our research because our results were inconclusive	1
Why they agreed to be interviewed	Wants to contribute to the progression of rangeland science	4
	Wants to know if tools work	3
	Knows and trusts the interviewee	3
	Research like this brings two different perspectives together	2
	Suspected their perspective was not being represented	2

Each quote, or meaning unit, was assigned a code that corresponded with a theme. Meaning units could have multiple codes. The codes presented here are derived from interview transcriptions of 11 interviews. Interviewees are color-coded by percentage–a dark box color means more interviewees had meaning units in their interviews that were assigned that code than a light box color.

interviewed still believed that Foxlights had the potential to be effective in conjunction with other strategies. Thus, the field of HWC would benefit from broadening established definitions of ecological effectiveness to include critical but often overlooked components of social acceptability, knowledge transfer, and dynamic socio-ecological systems. Researchers need to be aware that the social acceptability of a tool as well as systems-oriented approaches to tool evaluation are particularly relevant to stakeholder goals and perspectives when communicating science, and they should not expect the ecological success or failure of a given tool to be persuasive to a producer that is accustomed to working with complex systems in their husbandry. While our small sample size (11 interviewees) limits the universal applicability of our findings, the process by which we attained our results sheds light on how iterative collaboration can foster trust for research and promote goodwill between stakeholders. Our research also serves as a model for how a transdisciplinary approach can help future studies incorporate both social acceptability and ecological effectiveness into their methods of analysis.

The Value of a SES Approach to Tool Evaluation

Prior to learning the results of the Foxlight experiment, producers generally had an attitude of "anything helps." After we showed them the weak empirical results of the Foxlight experiment, interviewees in the second round of interviews still tended to believe that Foxlights had the potential to be effective. They acknowledged that deterrent effectiveness can be influenced by context (Eklund et al., 2017) and recognized that deterrents often work in association with each other to create an overall impact. It was clear that interviewees did not expect Foxlights to replace their preexisting strategies or even expect Foxlights to always work, likely because they recognized how environmental variability can impact an individual tool's ecological effectiveness. It is also possible that interviewees were more willing to think of Foxlights as effective because no sheep loss to coyotes occurred while in the line-of-sight of Foxlights over the course of the experiment, even though we clarified during interviews that low sheep mortality throughout the study period limited our ability to examine the effects of Foxlights on sheep predation. When asked about the results of our experiment, interviewees tended to focus on brainstorming new ways use the tool effectively instead of concentrating on the deficiencies of Foxlights. In other words, our empirical analysis did not give them reason to dismiss Foxlights as ineffective, but rather it gave them reason to lean into finding ways to make it more effective. Thus, empirical examples of effectiveness may not be what drives producer attitudes toward tools like Foxlights.

When it came to suggestions for different approaches to studying tools like Foxlights, interviewees tended to recommend approaches that reflected SES principles. They emphasized the importance of incorporating environmental variability, coyote ecology, and other management strategies into empirical evaluations of tools. The producers that we interviewed specifically identified that the established definition of ecological effectiveness that we presented them—the ability of Foxlights to deter coyotes from pastures—was inconsistent with their experience and way of thinking. An experimental method of isolating and testing a tool individually was not realistic to the interviewees' practice. Instead, they thought of tools as part of a complex and dynamic system that demanded an adaptive toolkit. This means that scientific reductionism does not always align with livestock producers' systems-oriented approaches to husbandry. We instead recommend systems-oriented evaluations of non-lethal tools, such as testing tools in combination as well as adjusting research variables to incorporate what producers identify as important. Analyzing multiple tools at once may enable producers to cycle through tools throughout the year, thus only applying tools when they can be most effective and avoiding habituation. Two interviewees also speculated that using Foxlights in combination with other tools and strategies would further allow coyotes to expect the association between risk and light through a process of "sensitization" (Blumstein, 2016; Gaynor et al., 2020).

Whether using multiple tools to sensitize carnivores or prevent habituation, few studies have examined multiple tools at once, but those that have offer promising results (Espuno et al., 2004; Lance et al., 2010; Garrote et al., 2015; Manoa and Mwuara, 2016; Miller et al., 2016; Moreira-Arce et al., 2018). For example, the Wood River Wolf Project used a range of non-lethal strategies and deterrents, including Foxlights, to lower sheep predation at sites in Idaho by 90% (Stone et al., 2017). The project operated on the assumption that no single deterrent can effectively reduce conflict, and the results revealed that tools must be consistently rotated, adapted to an ever-changing context, and analyzed holistically (Martin, 2020). Producers at HREC were actively employing other strategies throughout our study, something that potentially served as a confounding factor in this experiment, and our results would have benefitted from analyzing Foxlights in combination with other techniques (see **Supplementary Materials** for further discussion on the empirical results).

Research variables in future evaluations of non-lethal tools should better incorporate both the environmental and social factors that producers identify as important. Our study supports previous research that has found misalignment between producer perspectives on effectiveness and empirical analyses (Lance et al., 2010; Teague et al., 2013; Ohrens et al., 2019b). Management efforts should focus on bridging these domains of scientific and producer knowledge to inform decision-making. For example, another study involving HREC producers and their perceptions of risk demonstrated how the integration of producer perspectives into empirical assessments was essential to understanding coyote activity and deterrent use across a livestock operation (McInturff et al., 2020). We suggest that researchers select response variables that are informed by the interests of the stakeholders, not just what researchers can, or choose to, measure.

The Role of Social Effectiveness in Producer Decision Making

Our finding that ecological effectiveness alone is not enough to alter producers' attitudes builds off the work of Brunson (1992), who revealed how an overreliance on technical information can be detrimental to social acceptability for multiple reasons that our findings support, including: stakeholders are often already educated on the technical aspects of a subject, scientific jargon can alienate producers, overreliance on one "right answer" can fail to account for environmental heterogeneity, and that science cannot resolve differences of opinions that correspond with belief systems. Furthermore, livestock producers make decisions through holistic considerations of production dynamics by relying on both technical and cultural knowledge transfer. For example, a producer may learn about system dynamics from older generations of ranchers, their own experience of their land, and from scientific sources. Most importantly, producers *intentionally* engage with diverse knowledge sources when it comes to understanding the socio-ecological systems they operate within (Wilmer and Fernández-Giménez, 2015). The fact that scientific demonstrations of a tool's ecological effectiveness serve as only one source of information among many for producers underscores the need to incorporate social acceptability into tool evaluations.

Several elements that contribute to social acceptability were brought up in interviews. Interviewees emphasized that the messenger of scientific findings is important because there must be trust in who recommends a tool (Section Social Trust). In our study site, as for much of the American West, social trust between agricultural producers and scientists is low (Bonnie et al., 2020). Over half of the interviewees held negative attitudes toward science, which perhaps explains why other producers often serve as their most reputable source of information. But after working with us through multiple rounds of interviews, producers began coming to us for more information and discussion, demonstrating that research itself can build social trust if stakeholder perspectives are meaningfully included in the process. For example, all three of interviewees that worked at HREC expressed their suspicion of bias in science. Yet all three were among the interviewees who stated that they trusted the validity of our research, perhaps because they either played a role in the design of the experiment's methods, witnessed the research onsite, or like the other interviewees, participated in iterative interviews. When working with producers, researchers need to acknowledge their own positionality and account for the various ways they may be perceived. Investing in truly participatory science with stakeholders at multiple checkpoints throughout an experiment will both foster trust and address the perception that science or conservation can be biased or exclusionary (Hazzah et al., 2019). These findings underscore the value of stakeholder collaboration in informing social trust and social acceptability.

The role of attitudes, values, and systems in informing social acceptability also manifested in interviews. Interviewees elaborated on their personal values and identities, and how their attitudes toward lethal or non-lethal control often influenced their decision on whether to adopt certain methods (Section Attitudes and Values). They tended to express positive or negative attitudes toward the recent value shift in the American West. For example, when asked if the way rangelands are being managed is changing, one interviewee stated, "Over the course of time in California, people's emotions have taken over common sense. They let emotions drive their votes, and their votes have taken away all the effective means to control these predators. And that's the biggest frustration you have when you live in California."

Alternatively, a different interviewee on the same subject stated, "[The change] is a very emotional issue for a lot of these old guys. This is a human problem. It comes down to a sense of entitlement that this landscape should never challenge us and we should not have to coexist." Furthermore, the relevance of contexts and systems in informing social acceptability was certainly demonstrated within the interviews, as interviewees emphasized again and again the importance of systems-oriented examinations of HWC that account for available alternatives and environmental variability (Section Context and Systems).

Interviewees also described how they incorporated various ways of knowing into their decision-making process and relied on social networks (Section Information Transfer and Research Process). Our network sampling technique for contacting new interviewees may have even enabled us to access this knowledge network throughout our research process. As one interviewee stated, "There are people on the leading edge who are reaching out to other places and publications and are choosing [tools] they want to try. And then maybe there's enough of those people that it becomes a critical mass and then they push back on the mainstream [means of control]. It's pretty fascinating how knowledge transfers and how ideas spread." It is possible that some of our interviewees were opinion leaders on the "leading edge" of new technologies (Lubell et al., 2013), especially those that answered the question of "Why did you agree to be interviewed?" with statements that expressed their desire to either learn about new potential solutions or contribute to the progression rangeland science. We also found that social pressure from other producers played an important role in information transfer, although pressure only seemed to act on either lethal or non-lethal strategies but not between individual tools. Most interviewees emphasized that the public does not support lethal strategies, which is consistent with other studies (Naughton-Treves et al., 2003; Wolf et al., 2017; Diaz et al., 2020). Sometimes this pressure made interviewees inclined to select non-lethal tools, as one interviewee stated, "I think we're going to lose more and more of the lethal tools. And so it's really important to develop other tools that can work." In other cases, pressure had the opposite effect, as another interviewee stated, "I feel like if you give into the gimmick [and use non-lethal tools], then it's kind of a slippery slope and you're kind of giving up your option of really doing what really should happen." And finally, not only is there implicit evidence to suggest that our integrative research process that was built around producer participation contributed to the social acceptability of this tool, but producers explicitly stated that our transdisciplinary methods increased the credibility of this project (Section Information Transfer and Research Process).

Our findings also revealed how HWC mitigation has both economic and psychological dimensions within a given "taskscape," which is a social construction of a landscape that accounts for the lives, work, and practices that imbue the material landscape with meaning (Section Attitudes and Values). It is difficult, and perhaps impossible, to address one of these dimensions without acknowledging the other. For example, when asked how much they liked coyotes, one interviewee said, "I would [rate] coyotes zero. I've just seen so much gore and violence that it ceases to even be about money. It's about suffering." Livestock losses are also often unevenly distributed in space and time, obscuring the full impact. Uncertainty, and especially chronic uncertainty, has costs of its own. To exemplify this point, another interviewee said, "I'm always in a state of paranoia about that. And that's just the life of the shepherd. I hear any coyotes and I'm just like outside in my pajamas with my flip flops, trying to figure out where the sounds are coming from." While a loss of 1–3% of sheep crop to predation at our study site is a fairly standard industry loss, HREC producers explained that every predation event is a direct income loss of anywhere from $150–$500 per animal for producers, affects their job performances, and carries an emotional toll. These findings speak to the larger point illustrated by our research—ecological or economic data aren't the only forces driving attitudes when it comes to making decisions surrounding livestock loss and predation prevention. Strictly ecological or economic interpretations of the effectiveness of livestock protection tools will miss vital human dimensions, especially regarding social acceptability.

Recommendations

We recommend that researchers adopt the same systems-oriented approaches already used by producers to both test tools and communicate findings. This may involve analyzing deterrents in concert, accounting for broader environmental factors, and incorporating research variables that influence social acceptability. Researchers should continue to test tools, but also work closely with producers to solicit feedback. Establishing lending libraries of tools and partnering with producers to collect data will allow researchers to learn from their knowledge and insight, build trust, provide exposure to tools, and lower the barriers that enable access to certain tools. In the same way that app developers use business techniques to let users trial apps and "break" them in the real world, scientists could implement a similar, iterative approach with non-lethal tools, especially given that producers quite reasonably want to experiment with tools for themselves before forming opinions (Hazzah et al., 2019). We also recommend that our integrated and participatory approach be considered not just by other researchers, but also by land managers as part of their planning cycle. Land management agencies can use this iterative process to recognize a problem, identify potential solutions from stakeholder opinion and scientific literature, and then work toward a practical solution that is scientifically robust and culturally palatable. Establishing checkpoints with stakeholders along the way will allow managers to determine which solutions have social effectiveness, both in terms of solving the problem and aligning with stakeholder values. Work like this is already underway: the Wolf Advisory Group (WAG) within the Washington Department of Fish and Wildlife guides efforts to reduce conflict between wolves and livestock by inviting stakeholders from diverse backgrounds to participate within an inclusive decision-making framework (Wiles et al., 2011). Such approaches can guide tool adoption and promote sound practices, ultimately supporting conservation as well as livestock production goals. Examining systems-oriented approaches, account for social acceptability, and enabling practitioners test things for themselves may have much higher yields for the future of coexistence than endless science on particular tools.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article has been made available by the authors in the **Supplementary Material**. Additional data will be made available by the authors, without undue reservation, upon request.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by University of California, Berkeley Committee for Protection of Human Subjects (CPHS) and Office for Protection of Human Subjects (OPHS). The participants provided their written informed consent to participate in this study. Ethical review and approval was not required for the animal study because no animals were captured or handled, and the Foxlight experiment was non-invasive. Written informed consent was obtained from the owners for the participation of their animals in this study.

AUTHOR CONTRIBUTIONS

LV, AM, and KG contributed to the conception and design of the empirical study. LV, AM, KG, VY, and JB contributed to the conception and design of the qualitative interviews. KG, AM, and LV performed the statistical analysis. LV organized the database, conducted and analyzed interviews, and wrote the first draft of the manuscript. KG, AM, and LV performed the statistical analysis. AM, KG, VY, and JB wrote sections of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fcosc.2021.682210/full#supplementary-material

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