UNPACKING THE EVIDENCE OF HUMAN WILDLIFE CONFLICT INTERVENTIONS

THE CASE FOR REALIST SYNTHESIS

by

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EXECUTIVE SUMMARY

Conflicts between humans and wildlife have sweeping ramifications for global biodiversity conservation and sustainable development. With the current trajectory of human population growth and development, these conflicts will likely increase in both intensity and frequency.

Conflicts occur in multi-faceted, dynamic, and complex socio-ecological systems, and there are innumerable ways in which interventions can fail. Even interventions generally viewed as successful often yield mixed results in different contexts. The lack of reliable information on the effectiveness, costs, and side-effects of interventions erodes public support and ultimately undermines human-wildlife coexistence.

Realist synthesis is an explanatory method of evidence synthesis that may address shortcomings in traditional reviews of intervention effectiveness and better guide and improve approaches to conflict mitigation. Realist synthesis is well suited to address complex and interdisciplinary research questions but has seen little use in conservation. Through a worked example, this paper aims to describe and test realist synthesis to answer the question “How, under what circumstances, and for whom is virtual fencing likely to reduce human-wildlife conflict?”

Based on this synthesis, I demonstrate that realist approaches can support evidence-based decision making and practice by looking beyond whether the interventions work to explore how they work in different contexts and why. Furthermore, realist synthesis’ inclusivity and flexibility offer unique opportunities to develop more insightful and nuanced conclusions about complex interventions than those surfaced by traditional reviews.
BACKGROUND

Human-Wildlife Conflict

Rapidly expanding human populations and diminishing habitats put people and wildlife in frequent contact. Crop raiding, livestock depredation, property destruction, and other conflicts can devastate adjacent households (Nyhus, 2016). Resulting tensions can reduce local support for conservation and lead to retaliatory killing. Successful coexistence of humans and wildlife depends on how effectively the social, economic, cultural, and ecological costs of these conflicts are mitigated.

Governments, non-governmental organizations, and communities invest significant resources—time, money, and political capital—in attempts to reduce the risks or impacts of conflicts with wildlife. Selecting the most effective tool for a given situation is challenging. Robust evaluations of effectiveness remain surprisingly scarce (Eklund et al., 2017; Rose et al., 2019), and because multiple contextual factors—political, social, ecological, and economic—can influence effectiveness, what may work in one situation may not work in another. Poorly selected or improperly implemented interventions can undermine coexistence goals by increasing costs, reducing trust, and failing to protect lives and livelihoods (Luc Hoffman Institute, 2020; Nyhus, 2016).

Policymakers, conservation practitioners, communities, and funders urgently need better data on conflict interventions to support and improve evidence-based policy, practice, and decision making (Cooke et al., 2017). Without access to reliable evidence, conservation practitioners are forced to rely on limited and/or experience-based approaches that may be ineffective or destructive (Sutherland et al., 2004).
The Shift from Experience-Based to Evidence-Based

Until relatively recently, the field of medicine was fraught with similar issues. A lack of consistent, accessible, and relevant scientific evidence resulted in broad variations in medical care, including the “underuse, overuse and misuse” of diagnostics and treatments (Chung & Ram, 2009). Impacts associated with this detachment of evidence and practice caused American medicine to shift from experience-based to evidence-based practice and policy. The change has been called the “effectiveness revolution” in American medicine (Chung & Ram, 2009).

“As it is currently defined, the practice of evidence-based medicine involves systematic and judicious application of the best available research evidence in the clinical care of individual patients and patient groups.” (Davidoff, 2008, p. 30)

Systematic reviews of the available research swiftly became medicine’s fundamental tool of choice. Between 1986 and 2015, researchers published more than 266,000 systematic reviews (Ioannidis, 2016). Two methods of systematic review are most common: numerical meta-analysis and narrative review:

a. **Numerical Meta-Analysis.** Meta-analysis is based on three steps: classify, tally, and compare (Pawson, 2006a). In these analyses, results from evaluations—or the “net effects”—of different interventions are mathematically compared to identify which intervention “works best” (Figure 1). While one dogma argues that results of meta-analysis represent the “best” evidence (Berlin & Golub, 2014), critics contend that the aggregation process of meta-analysis has the potential to meld mechanisms of change, oversimplify outcomes, and conceal contexts (Pawson, 2006a).

Sample Meta-Analysis - Forest plot of comparison: Sleep quality: listening to music versus control" (Jespersen et al., 2015)

<table>
<thead>
<tr>
<th>Study or Subgroup</th>
<th>Music Listening</th>
<th>Control</th>
<th>Mean Difference</th>
<th>Mean Difference</th>
<th>Risk of Bias</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Total</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Heavner 2000</td>
<td>3.27</td>
<td>1.8</td>
<td>35</td>
<td>5.9</td>
<td>2.16</td>
</tr>
<tr>
<td>Jespersen 2012</td>
<td>11.69</td>
<td>4.11</td>
<td>9</td>
<td>12.67</td>
<td>2.16</td>
</tr>
<tr>
<td>Kellich 2003</td>
<td>5.8</td>
<td>3.2</td>
<td>32</td>
<td>8.1</td>
<td>3.4</td>
</tr>
<tr>
<td>Lai 2005</td>
<td>7.13</td>
<td>3.19</td>
<td>28</td>
<td>10.97</td>
<td>2.75</td>
</tr>
<tr>
<td>Shum 2014</td>
<td>5.9</td>
<td>2.4</td>
<td>28</td>
<td>9.5</td>
<td>2.6</td>
</tr>
<tr>
<td><strong>Total (95% CI)</strong></td>
<td><strong>534</strong></td>
<td><strong>130</strong></td>
<td><strong>100.0%</strong></td>
<td><strong>100.0%</strong></td>
<td><strong>-2.80 [-3.42, -2.17]</strong></td>
</tr>
</tbody>
</table>

Heterogeneity Test: $I^2 = 0.60$, $Ch^2 = 2.59$, df = 4 ($P = 0.60$); $I^2 = 6%$
Test for overall effect: $Z = 8.77$ ($P < 0.00001$)

Risk of bias legend:
- A: Random sequence generation (selection bias)
- B: Allocation concealment (selection bias)
- C: Blinding of participants and personnel (performance bias)
- D: Blinding of outcome assessment (detection bias)
- E: Incomplete outcome data (attrition bias)
- F: Selective reporting (reporting bias)
- G: Other bias

b. **Narrative Review.** Not unlike meta-analysis, a narrative review aims to compare a family of interventions in hopes of identifying the most effective. Since such reviews incorporate a narrative component, they are said to maintain a “ground-level view” (Pawson, 2006a), explaining what happened with each program
and why the most effective intervention was successful. But in trying to capture common denominators of hundreds of studies, narrative reviews often lose important details, and recommendations end up overcontextualized (Pawson, 2006a).

Inarguably, there are advantages of going beyond solitary evaluations when examining a body of literature on a given intervention or program. Recognizing this, an increasing number of disciplines now utilize systematic reviews to evaluate the effectiveness of their programs.

Sutherland, Pullin, and Knight were among the first to champion the systematic review and collation of evidence in conservation (Pullin & Knight, 2001; Pullin et al., 2003; Sutherland et al., 2004). Since then, the use of systematic reviews in conservation biology has accelerated. The Collaboration for Environmental Evidence, a collective based on the Cochrane Collaboration model for medicine, was created to provide guidance and support for the production of systematic reviews (Collaboration for Environmental Evidence, 2020). Conservation Evidence, based at the University of Cambridge, provides online tools to support decisions about how to maintain and restore global biodiversity, including summarized evidence from the scientific literature about the effects of conservation interventions (Conservation Evidence, n.d.). Between 1998 and 2017, 79 systematic reviews were published in 28 conservation biology journals (Boyce, 2019).

The authors of one of these reviews assert that the systematic reviewing process “is actively increasing the efficiency and trustworthiness of biodiversity conservation” (Eklund et al., 2017). “Efficiency” is an interesting word choice, as it typically refers to economic gains—that is, the ratio of useful output to total input, be it price, cost, or performance. But is that the appropriate measure of biodiversity gains?

“Systematic reviews of the available research have become the instrument of choice for evidence based policy. But it is an instrument in the making. Whilst it is greatly admired, it is now widely recognised that the meta-analysis approach of evidence based medicine cannot provide a model for systematic review that will be as effective in other policy domains. Clinical evidence is positively copious and decidedly sleek. By and large, treatments are well defined, trials are tightly controlled and replications abound. But as soon as one moves beyond the medical field and into welfare, education and criminal justice policy, the picture changes. Initiatives become complex, impossible to manipulate experimentally and the devil to replicate.” (Pawson, 2002, p. 2)

Circling back, can conservation—often placed at the intersection of three rings representing “economy, society, and the environment” (Martin et al., 2016)—be characterized as “decidedly sleek,” “tightly controlled,” and where “replications abound”? I’d argue no. Conservation interventions are often complex and act in or on large, often messy, and even more complex social and ecological systems. Such complexity requires prioritizing explanation over certainty and exploring the contextual boundaries of an intervention, moving past the question of “what works” and attempting to answer “what works for whom, in what respects, to what extent, in what contexts, and how” (Pawson, 2006a).

**Realist Inquiry**

“Realism holds that mechanisms matter a great deal because they generate outcomes, and that context matters a great deal because it changes (sometimes very dramatically) the processes by which an intervention produces an outcome. Both context and mechanism must therefore be systematically
researched along with intervention and outcome. By implication, research or evaluation designs that strip away or “control for” context with a view to exposing the “pure” effect of the intervention limit our ability to understand how, when and for whom the intervention will be effective.” (Wong et al., 2011, p. 90)

Pawson and Tilley (1997) were the first to advance program and policy evaluation through a realism lens. They argued that to be useful to decision makers, program and policy evaluations must answer “what works for whom and in what circumstances.” Realist synthesis is a form of theory-based evaluation grounded in the philosophy of science and social science (Pawson, 2006a). The approach is based on “critical realism,” initially developed by the philosopher Bhaskar (1989), which holds that science advances by uncovering “generative mechanisms.” Through an investigative approach, realist reviews attempt to expose the underlying mechanisms and contexts that influence interventions in complex systems.

Rather than identifying replications of the same intervention, as is done in traditional systematic reviews, realist evaluators iteratively seek out wide-ranging contexts in which the same mechanism has been attempted (Pawson, 2006a).

**Realist Synthesis Methodology**

Realist methodology begins by formulating theories that help to explain the mechanisms by which interventions or programs might work. These candidate program theories are then used to focus the research question and develop protocols for data collection (Pawson & Tilley, 1997). A range of both quantitative and qualitative data is collected and tested against the candidate program theories through an interpretive and iterative process (Pawson, 2006a).

The final research product from realist evaluation is a refinement of program theories that addresses the questions of “what works for whom, under what circumstances, why and how” (Pawson, 2006a). Supporting evidence includes not only primary outcome data but also the reviewer’s interpretations of these outcomes.

**Figure 3: Sequence of Realist Synthesis**, Adapted from Pawson (2006a)
Applications of Realist Synthesis

Realist approaches are well suited to address more complex and interdisciplinary research questions. They’re particularly appropriate for evaluating three types of interventions: 1) those that seem to work, but “for whom and how” is not well understood; 2) interventions that have yielded mixed results; and 3) interventions that will be scaled up, so as to understand how to adapt them to new contexts (Westhorp, 2014).

Realist synthesis is increasingly used to synthesize research in education, mental and physical health, social services, criminal justice, and health policy. Despite this, the penetration of realist approaches into the environmental sciences has been limited. Based on a 2020 Google Scholar search, fewer than 10 environmental realist reviews have been published to date. Of these, only three could arguably be considered conservation-related topics, and none addresses interventions aimed at lessening human-wildlife conflict.

Worked Example: Virtual Fencing

What follows is a worked example of taking a realist approach to evaluating and synthesizing evidence on virtual fencing applications in wildlife management and animal husbandry. Through an exploration of the links between mechanisms, contexts, and outcomes, I will help answer the research question: “How, under what circumstances, and for whom is virtual fencing likely to reduce human-wildlife conflict?”

VIRTUAL FENCING

Fencing, bomas, and other physical barriers have successfully reduced the impacts of human-wildlife conflicts (Sutton et al., 2017), but evidence suggests they’re costly to maintain and may intensify conflicts and overuse of habitat in neighboring areas (Osipova et al., 2018), isolate genetics, and disrupt dispersal and migration routes (Creel et al., 2013).
A virtual fence can also function as a barrier, boundary, or enclosure but without the need for a physical structure on the landscape (Jachowski et al., 2013; Umstatter, 2010). In the broadest sense, a virtual fence could be as simple as a passive biological barrier or a sensory deterrent, such as a spray that keeps deer out of a garden. By forming an invisible barrier around the garden, these repellents “direct” the movement of free-ranging deer and thus act as a virtual fence. For the purposes of this realist synthesis, however, I’ll use a narrower view, focusing on real-time, proximity-based virtual fencing.

Real-time virtual fences rely on proximity-based tracking systems to alert or activate when free-roaming animals cross predefined management boundaries. The technology typically takes one of two forms: 1) When a virtual fence is breached, an animal-mounted GPS tracking collar transmits location data by cell phone, initiating management intervention or action—for example, hazing an animal back within the boundaries—or 2) the technology activates sensory deterrents, such as an audio cue paired with an enforcer, when the animal crosses the virtual fence line (Jachowski et al., 2013).

For wildlife management, virtual fencing provides a number of benefits over traditional physical barriers: First, boundaries can be rapidly modified, both spatially and temporally. Second, virtual fences do not restrict the movement of non-target species. Third, they permit research, monitoring, and adaptive management to be integrated. Finally, they reduce installation costs and eliminate the high cost of maintaining, replacing, and removing traditional fences (Anderson, 2007; Jachowski et al., 2013; Umstatter, 2010).

The technology’s potential to improve land management, reduce costs, and mitigate human-wildlife conflicts has piqued the interest of both agricultural producers and conservation practitioners.
METHODS

“There are significant differences from other review methods, however, most notably in that this sequence is iterative—it is travelled repeatedly. The learning from one tranche of studies provides provisional explanations and new clues that can be further refined by focusing and refocusing the searching for crucial primary materials. Learning accumulates as the review travels around the research cycle.” (Pawson et al., 2016, p. 2)

CONCEPT MINING AND THEORY FORMALIZATION

Preliminary Search and Theory Elicitation

I began with an initial scoping review to get a broad overview of the available literature on virtual fencing systems and to identify candidate theories with potential explanatory value. This process, known as “theory elicitation,” focuses on locating the “proposed diagnoses and planned remedies that have gone into the making of an intervention” (Pawson et al., 2016, p. 2). Beyond sorting through the body of literature on the many uses of virtual fences, I reviewed documents related to conditioning stimuli, learning, and habitation to modify, extend, and further specify candidate theories that explain virtual fencing mechanisms and objectives. Varied objectives could be discerned; different virtual fencing applications sought improvements at the technical, cognitive, and structural levels. Throughout the search, I progressively refined the review question to focus more specifically on how virtual fencing could help mitigate human-wildlife conflict.

Searching for Primary Studies

With a clearer and broader picture of what virtual fencing is intended to do, I moved on to gather evidence on the implementation and effectiveness of various interventions. I searched the literature using both Google Scholar and traditional search engines to locate qualitative and quantitative primary research, papers, reports, and reviews that would enable testing of the candidate theories. Experimental and quasi-experimental evaluations of human-wildlife interventions remain scarce (Eklund et al., 2017), and they are even scarcer for novel applications like virtual fencing, so the search included non-published “gray” literature, such as manufacturers’ specifications, consultations, reports, demonstrative accounts, critiques, etc.

A search strategy was developed, using terms and synonyms describing the relevant applications of virtual fencing, including various combinations of the following search terms: “virtual fence,” “VF,” “RTVF,” “geofence,” “aversive geofencing devices,” “virtual barriers,” “non-physical barriers,” “proximity-based alarms,” and others. The initial search for candidate program theories also yielded more specific search terms. For instance, a search for virtual fencing to control livestock revealed the importance and sequence of “associative learning” to produce an “avoidance response.” These terms were then used to investigate further pieces of evidence, turning increasingly to hand searches and “snowballing”—that is, pursuing references of references. These specialized searches were often revisited in the synthesis and analysis stages in order to clarify context and outcomes.

Quality Appraisal
As the name suggests, traditional systematic review follows a disciplined, formalized, transparent, and “ruthlessly methodical” sequence of steps in order to be seen as producing a cumulative, objective, and trustworthy body of knowledge (Pawson, 2006b). Appraising evidence quality occurs early in the process, before synthesis, which Pawson (2006a) characterizes as an appraise-then-analyze sequence. The research quality of the primary studies is appraised, and only those deemed to be of high quality are analyzed; the remainder are discarded.

Pawson (2006b) warns: “There are often nuggets of wisdom in methodologically weak studies and systematic review disregards them at its peril.” To this end, realist synthesis promotes a non-sequential or parallel processing approach: analysis-and-appraisal, allowing for the possibility that “good” evidence might be uncovered in “bad” research.

Likewise, realist synthesis rejects systematic review’s hierarchy of evidence, whereby randomized-control trials secure higher standing than process evaluations, qualitative case studies, expert opinion, and others. Many argue this hierarchy undervalues the contributions of other research perspectives:

“Qualitative knowledge is absolutely essential as a prerequisite foundation for quantification in any science. Without competence at the qualitative level, one’s computer printout is misleading or meaningless. We failed in our thinking about programme evaluation methods to emphasise the need for a qualitative context that could be depended upon... To rule out plausible hypotheses we need situation specific wisdom. The lack of this knowledge (whether it be called ethnography or program history or gossip) makes us incompetent estimators of programme impacts, turning out conclusions that are not only wrong, but often wrong in socially destructive ways.” (Campbell, 1984, p. 366)

With respect to this synthesis, two standards informed my decisions about quality: 1) Relevance. A primary study had to provide relevant evidence. Making this determination required a large amount of preliminary reading and making study-by-study decisions on relevance. 2) Rigor. The study had to be of sufficient standard within type, be it qualitative or quantitative, a process evaluation, or a randomized control trial, and so on.

**Extracting the Data**

In traditional systematic review, researchers dissect all included studies using a standard data-extraction form to mine the same information from every study. In realist synthesis, not all studies will address every aspect of every program theory. Generally, evidence of causal structure, outcome patterns, implementation, and context are revealed by different research strategies and found in different types of literature.

In place of a standardized form, I developed and continuously adjusted a table to record extracted data and aid in the sorting and annotation of data source materials. I utilized coding techniques to track the mechanisms, contexts, outcomes, and other relevant information on the intervention and to map studies to evidence to program theories.
PROGRAM THEORIES

The process of concept mining and theory elicitation generated 12 program theories—exploratory hypotheses—on what it is about virtual fencing that works for whom and under what circumstances. These were continuously refined throughout the evidence synthesis.

1. Successful virtual fencing interventions have to supply the appropriate type, sequence, and balance of change mechanisms that align with the behavior, physiology, ecology, and legal protections of the intended targets.
2. Unsuccessful interventions follow the application of inappropriate, inadequate, or ill-timed mechanisms.
3. The targeted species’ behavior, physiology, and ecology heavily influence the effectiveness of virtual fencing.
4. Interventions that initially are easy to implement and deliver well will be difficult to sustain if animals habituate to them.
5. Stimulus type influences habituation, but the precise selection, combination, and configuration of stimuli to minimize habituation depend entirely on the target species.
6. Interventions that rely on learning association may be best suited to slowly reproducing, long-lived, social structured, and/or group-living species.
7. Virtual fences can give communities a feeling of control over natural resources.
8. Human behaviors, attitudes, and actions can dramatically affect the effectiveness of an intervention, even if the actors are not directly involved in the conflict or intervention.
9. Socio-cultural and technological contexts can heavily influence the effectiveness of virtual fencing applications that depend on user response (for example, early-warning systems).
10. Integrating education, outreach, and community-based social marketing can increase the effectiveness of virtual fencing.
11. Virtual fencing that depends on or increases the need for on-the-ground management will be difficult to maintain and sustain.
12. Cost is often a barrier to widespread implementation of virtual fencing, even for interventions that have been proven effective.
EVIDENCE SYNTHESIS

“The purpose is to articulate underlying programme theories and then to interrogate the existing evidence to find out whether and where these theories are pertinent and productive. Primary research is examined for its contribution to the developing theory. The overall intention is to create an abstract model of how and why programmes work, which then can be used to provide advice on the implementation and targeting of any novel incarnation of the intervention.” (Pawson, 2006a, p. 74)

The ultimate objective of realist synthesis is explanation building (Pawson, 2006a). For instance, in reviewing virtual fencing applications that seek to modify animal behavior, I began by discovering a study claiming that the long-term effectiveness of virtual fencing depends crucially on animals not becoming habituated. This conclusion was strengthened as I uncovered further primary studies providing evidence of the same proposition across multiple species types. This explanation, however, suggested the relationship between stimuli type and habituation. And this directed the review to further studies and supplementary explanations about mechanisms of habituation, animal sensitivity to different cues and signals, and learning pathways.

The evidence synthesized below is presented in this incremental and accumulative style. The reporting and analysis of the primary studies is organized into three blocks: Block 1 examines ground-based transmitter-activated sensory deterrents that support ecological goals. Block 2 looks at animal-mounted GPS tracking systems used in livestock management and husbandry. Block 3 focuses on real-time early-warning systems deployed to prevent or minimize human-wildlife conflict.

BLOCK 1: GROUND-BASED SENSORY DETERRENTS

This group of studies looks at “virtual fencing” interventions that utilize ground-based transmitters to activate sensory deterrents to control or modify wildlife behavior. This initial group helped establish the precise changes that result from successful interventions, revealed what the devices must do to bring about these changes, and suggested which species are best able to receive the mechanism of change. None of these studies involved directed human action or response, thus controlling for an influential set of variables.

Case 1.1: “Roadkill Mitigation: Trialing Virtual Fences on the West Coast of Tasmania, Australia”

In this trial, Fox et al. (2018) look at an application of virtual fencing to mitigate roadkill in Tasmania, Australia. The island state has the country’s highest incidence of wildlife roadkill, and several of its endemic species are highly vulnerable to collisions with vehicles. The trialed virtual fence uses an array of electronic devices. At night, a car’s headlights trigger a combination of strobing amber and blue LED lights and a high-pitched alert, warning wildlife that a vehicle is nearby. Though not well supported by published studies, the authors purport that the technology has reduced mortality of deer and wild boar by 77% to 100% across multiple sites in Austria, where the devices were developed.
Between 2014 and 2016, the authors trialed the intervention at a single 13-km stretch of road to determine whether the devices mitigate road deaths of Australian wildlife, in particular such threatened marsupials as the eastern quoll, eastern barred bandicoot, and Tasmanian bettong, as well as the endangered Tasmanian devil, a species on the IUCN Red Listed. Populations of the devil have plummeted over the past 20 years, due in large part to an extraordinarily lethal and contagious cancer. The government estimates that vehicles claim an additional 300 to 450 devils annually. Beyond having species-persistence and conservation implications, high roadkill rates reduce the visitor experience and thus may have economic implications as well.

The 3-year, quasi-experimental study consisted of three phases: a pre-installation survey, a comparison of roadkill rates before and after installation, and a longer comparison of fenced versus unfenced sections of road. Prior to installation of the virtual fence, data were collected daily for four months (October 2013 to January 2014), at the time of the year, according to the authors, when the most roadkills occur. The observer—typically the same individual, highly trained in wildlife identification—recorded the distance of each roadkill from the starting point, as well as the species of each roadkill, if known. Once recorded, carcasses were then removed from the road to prevent double counting. This initial dataset was used to determine the background level and distribution of roadkills and to determine whether the area identified for installation of the virtual fence had a markedly different roadkill rate than the rest of the road. In February 2014, devices were initially installed along a 3.2-km stretch of the road and later extended by an additional 1.9 km. Devices were installed on both sides of the road but staggered to allow a 50-m distance between devices on the
same side of the road and only a 25-m distance between devices on opposite sides of the road. The units were pointed so that the emitted light was directed away from the road surface and toward the road verge. The result is a “virtual fence” of noise and light when the devices are triggered by car headlights.

The authors next compared the roadkill rate each month before and after the fences were installed, to determine if there was any difference before and after installation. Finally, the authors compared roadkill rates inside the fenced and unfenced areas for the entire 13-km and 3-year monitoring period. By pairing roadkill rates for each month, seasonal differences in roadkill rates were taken into consideration in the analysis.

The authors’ data show a significant reduction in the total number of animals killed on the road, up to 50% for the most commonly affected species:

![Image of roadkill events table]

These findings suggest, in the authors’ words, “enormous potential to substantially reduce roadkill rates”:

> “While there was no spatial replication in this trial, a reduction in total roadkill rate, and in the most commonly affected species, by 50% suggests that these devices have enormous potential to substantially reduce roadkill rates. […] The obvious reduction in roadkill in this trial of virtual fence technology is encouraging and should support roll-out of these devices at other identified roadkill hotspots in Tasmania, which, with concurrent monitoring, may be used to demonstrate the widespread applicability of the device in reducing roadkill state-wide.” (Fox et al., 2018, p. F)

Fox and her colleagues concentrate on the roadkill events by species, with particular emphasis on the mechanics and measures of the fenced and unfenced, and the before-and-after comparisons. The study offers little more than hints of explanations for the differences in roadkill rates. In realist synthesis, the reviewer’s task is building an explanatory model. Pawson (2006a) writes: “Going beyond reported findings and into their interpretation is the whole point. This exploration may go so far as developing, clarifying and perhaps even challenging the original analysis.”

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*The ‘Other’ category includes birds, blue-tongued lizards and cats.*
To this end, the question I’m left with is, Why did the intervention fail for 102 animals? The authors make no effort to hypothesize. Typically, one would look for influences of independent variables, but the study’s authors closed off this avenue of inquiry by assuming up front that vehicle speed, vehicle weight, traffic volume, and road characteristics would be alike in all comparisons:

“The road is straight and flat, with a few undulations. The speed limit along this road is 100 km/hour. [...] All three analyses assumed that roadkill events are missed at random, and not dependent on species, or different survey conditions such as weather, observer, etc., and any detected difference in rates of roadkill are attributable to the fence, and not for any other reason such as car use along the road changing (e.g. any car that will drive through both the fenced and unfenced stretches of road was assumed to travel at a similar speed in both areas).” (Fox et al., 2018, p. C)

Three months after publication, Coulson and Bender (2019) pointedly critiqued the study. With respect to the conceptual basis of the virtual fence, they raise concerns that the stimuli emitted by the virtual fence may not be suitable for the target species. As described by the authors, relatively little is known of the visual system of marsupials, and no studies of spectral sensitivity in Tasmanian marsupial species have been conducted. Of the marsupial vision systems that are known, none has rod or cone pigments in the red band, suggesting it’s unlikely any marsupial could detect the virtual fence’s amber light (591 nm wavelength). The blue light and acoustic signals, Coulson and Bender (2019) concede, are:

“(A) reasonable match to the peak sensitivity of short-wavelength cones in both dichromatic and trichromatic marsupials suggesting that all the Tasmanian species would be able to detect this light if it were bright enough to activate their cones. [...] Likewise, both sound frequencies of the virtual fence are suitable for Tasmanian species, of which much more is known of their auditory systems, notably behavioral and electrophysiological responses to various frequency sounds. But as both the light and sound stimuli are artificial and lack biological significance, the authors assert the technology will be prone to habituation once novelty wanes.” (p. 124)

They go on to document a total of eight methodological flaws, ranging from imprecise measurements, confounding effects of treatments, low statistical power, violation of test assumptions, and failure to consider habituation. They urge caution in interpreting the findings of the study:

At best, this trial should be considered a pilot study, which has generated data on roadkill rates, albeit with poor spatial resolution and no measure of sampling variation. These data could make a useful contribution to the design of future trials, with acceptable statistical power, for a robust assessment of the “virtual fence”. (Coulson & Bender, 2019, p. 127)

While this and other appraisals of Case 1.1 have questioned some of the authors’ analyses, the findings are not inconsistent with many of the initial program theories under review. In particular, the example confirms the need for stimuli to be appropriately configured to the behavior, ecology, and physiology of the target species. Habituation is clearly a key factor to be investigated through further primary studies.

**Case 1.2: “A Trial of a Solar-Powered, Cooperative Sensor/Actuator, Opto-Acoustical, Virtual Road-Fence to Mitigate Roadkill in Tasmania, Australia”**
This field trial is similar to the one described above. Englefield et al. (2019) test the effectiveness of virtual fencing along a 4.5-km stretch of a Tasmanian highway over 18 weeks. Though the authors employed identical technology, they were unable to replicate the previous study’s 50% reduction in roadkill.

The authors subdivided the 4.5-km road segment into six equal sections. They monitored roadkill by species for a total of 126 days. Alternate sections were periodically switched on or off, according to a variation of multiple Before-After-Control-Impact and crossover experimental designs that divided monitoring into five periods.

Their research strategy came as near as possible to a randomized, controlled trial. Unlike Case 1.1, the authors employed both true spatial replication and temporal replication and therefore provided a valid comparison at both scales.

The authors modeled the 30 aggregated values of daily roadkill counts (from the six sections over the five periods). Bennett’s wallabies, Tasmanian pademelons, and common brush-tail possums accounted for the majority of the 174 total road-killed animals. The findings were not statistically significant for each of these three species under all three scenarios. Adjustment for spatial and temporal trends also failed to detect a significant effect of the virtual fence.

The differences in the results of the two studies raised further questions about the veracity of Fox et al.’s results (Case 1.1) and, more broadly, the efficacy of these virtual fence devices. The question remains: In what circumstances and for what species do these tools effectively mitigate roadkills?

In contrast to Case 1.1, the authors detailed a number of influencing independent variables, describing the road characteristics of the study site as follows:

“The 4.5-km section of highway is mostly straight with some sweeping bends. Proceeding north-east to south-west, the highway has a gentle decline but becomes steeper over approximately the last 1.5 km. Rough pasture abuts the highway, with intermittent copses of eucalypts and light undergrowth either side of the clear gravel and grassy verges, ranging in width from approximately 5 to 15 m. The vegetation becomes more dense woodland alongside the steeper south-western sections.” (Englefield et al., 2019, p. 3)

The road in Case 1.1 was straight and flat with a few undulations, and of relatively consistent habitat type.
This study period was far shorter, only 18 weeks versus 3 years in Case 1.1, yet the roadkill rate was much higher (9 and 5 times higher for Bennett’s wallabies and Tasmanian pademelons, respectively). Brush-tailed possums were a major contributor of mortality in this study, but only a minor factor in Case 1.1. All three species are nocturnal or crepuscular feeders, so most roadkills occur between dusk and dawn. The authors suggest the differing habitats of their site and that of Case 1.1 may have contributed to the variations:

*The Arthur Highway on the west coast of Tasmania runs through coastal scrubland whereas the Huon Highway of South East Tasmania runs through farmed grazing land combined with native bushland. Larger population sizes due to the greater availability of nearby pastureland and native bushland for grazing would be expected at the Huon Highway site.* (Englefield et al., 2019, p. 11)

The authors explored why the virtual fence may have been ineffective in this context. According to the manufacturer, “device effectiveness is speed dependent” (IPTE - Traffic Solutions Ltd., 2019). The sensors have a range of 150 m for headlights set to low beam. Assuming a maximum speed of 90 km/hr, animals have 6 s to react and leave the road.

In contrast to Case 1.1, the authors employed a traffic counter that “accurately approximates the number of vehicles using the full extent of the trial site, their speed, and time of their passage on a continuous basis.” Hobday and Minstrell (2008) previously demonstrated that, based on driver detection distances, nighttime driving speeds must fall below 80 km/hr to reduce roadkill rates.

Average speeds recorded during this trial were well above 80 km/hr; the highest recorded speed was 189 km/hr. The virtual fence device is triggered by headlights at a distance of 150 m. Thus, at 189 km/hr, the vehicle would reach an animal at the trial site in 2.85 s, and at 140 km/hr, the vehicle would reach the animal in 3.85 s. Such delays are not sufficient to allow an animal to react and leave the road. The authors conclude the virtual fence would be ineffective at these higher speeds.

At 80 km/hr as suggested by Hobday and Minstrell, it would take 6.8 s for a vehicle to reach an animal, which is enough for it to react and leave the road. But the authors question whether the sound and light stimuli of the virtual fence produced such a reaction.

This paper amplifies the necessity of tightly correlating intervention mechanisms to the target species. We also see the potentially significant role of an external actor, notably vehicle drivers. The study thus confirms Program Theory 8, which suggests that human behaviors, actions, and attitudes can diminish effectiveness, even those acting outside of the intervention. The study hints at the potentially important and complementary role of education, outreach, and community engagement (Program Theory 9).

**Case 1.3: “Sounds Scary? Lack of Habituation Following the Presentation of Novel Sounds”**
In Biedenweg et al. (2011), the evidence shifts away from virtual fencing to other contexts. This quantitative study attempts to tease out whether natural or artificial sounds elicit stronger aversive behaviors and whether animals habituate as frequency of playback increases. The study also provides further evidence on the importance of species-specific stimuli.

The authors looked at western grey kangaroos, a species frequently implicated in conflicts with farming and ecological restoration. Non-invasive methods of managing kangaroo conflicts do not exist. The authors explored using acoustic signals to produce anti-predator behavior in kangaroos, as a means to mitigate conflict humanely.

In mammalian prey species, auditory signals of danger—such as alarm cries of conspecifics or sounds of predators—are particularly important to group-living animals that cannot fully utilize vision, such as fossorial (burrowing) and/or nocturnal animals. Olfactory signals are also critically important for predator detection.

When exposed to fear-eliciting stimuli, “kangaroos may increase vigilance, decrease foraging and even shift habitat utilization by retreating from high risk areas” (Biedenweg et al., 2011). The authors theorize that a better understanding of their sensitivity to different signals may aid the development of non-invasive deterrents.

Contrary to previous studies and to the authors’ predictions, the results showed:

“(K)angaroos responded most aversively to the playback of an artificial signal, the bull whip crack, and failed to rapidly habituate to this novel sound. […] Playbacks of natural foot stomp were not entirely ineffective, just less dramatic than expected. In a natural environment, animals may require visual feedback to elicit the strongest repellent response from audible alarm behaviors.” (Biedenweg et al., 2011, p. 5)

This study provides useful data on habituation. Most notably, the results call into question the assertion by Coulson and Bender (2019) that “both stimuli are artificial and lack biological significance, so will be prone to habituation once novelty wanes”. It’s seemingly clear there is no one-size-fits-all-species formula for stimuli with respect to both efficacy and the likelihood of habituation. Again, we see the importance of selecting and configuring stimuli with evidentiary support for maximal effect on and minimal habituation of the target species.

**Case 1.4: “Effectiveness of an Acoustic Wildlife-Warning Device Using Natural Calls to Reduce the Risk of Train Collisions with Animals”**

Animal-train collisions can substantially affect some wildlife populations. In this study, Babińska-Werka et al. (2015) tested the effectiveness of a device that produces natural auditory signals to reduce the risk of trains striking animals.
The UOZ-1 devices (NEEL, 2020) produce auditory signals—natural warning calls of animals—immediately before a train approaches the site. Sounds included the warning call of the jay (a predator of red squirrels and hares), the cry of a frightened brown hare, the growl and bark of a dog (a top carnivore in central Poland), the howl of a wolf, the distress call of a roe deer, and the squeal of a wild boar. The authors theorized that the animals would perceive these sounds as legitimate and flee as they would if coming across a natural predator or another danger.

At two study sites in Poland, the authors used digital cameras to record animal activity 24 hr/day over approximately 4 years. The aim was to determine the reactions of animals to the sound signals produced by the device. The researchers recorded the frequency and speed of reactions when devices were switched on and switched off and compared. Measuring the reactions of the animals over multiple years also allowed the researchers to determine if the animals became accustomed to the sounds.

When a train approached the site, signals were emitted for a period of time. Between 85% and 93% of the animals escaped, depending on the species. For roe deer, the most common species, the authors further compared the animals’ reactions when a train approached and the device was on with times when the device was switched off. Deer escaped more often and their reaction to an oncoming train was 20 s faster when the signals were emitted. The authors tested for and saw no evidence of habituation by comparing the percentage of animals that showed no reaction at the start and end of the 4-year study. In the authors’ words:

“The results of this research indicate that the UOZ-1 is more effective in reducing the risk of train–animal collision, by prompting animals to leave the railway track faster and with greater frequency, than only the sound of an oncoming train.” (Babińska-Werka et al., 2015, p.6)
Importantly, animals do not abandon the section of the railway line where the UOZ-1 devices are installed. They continued to use surrounding areas to feed and crossed the tracks between train runs.

This study exemplifies the value of virtual fencing when tied with biologically appropriate stimuli. Despite evidence of effectiveness, the device has been implemented at only a handful of sites. This is the first direct evidence of cost barriers to implementation, as hypothesized in Program Theory 12.

BLOCK 2: LIVESTOCK MANAGEMENT STUDIES

This next set of primary studies comes from the world of agriculture, where virtual fencing is used to confine or move domesticated livestock without fixed fences. The purpose of this short section is to explore theories related to stimuli and learning. And in this respect, studies of domesticated livestock at an agricultural research facility present unique opportunities, as well as a greater level of methodological rigor, since the setting is controlled.

Case 2.1: “Associative Learning by Cattle to Enable Effective and Ethical Virtual Fences”

Virtual fencing systems for livestock typically pair an audio cue with an enforcer, principally an electric shock. As such, their use has raised ethical and animal-welfare concerns, particularly in Europe and Australia, where adoption of the technology has started to take off.

Lee et al.’s study (2009)—conducted at a CSIRO\(^1\) agricultural research site—investigated whether cattle could be controlled without a fixed fence through audio and electric stimuli applied via a GPS collar. To do so in an ethical manner requires facilitating associative learning such that the animals can understand and learn the desired behavior. The headline result is that “the study demonstrates that the appropriate use of an audio cue is an effective conditioned stimulus for virtual fencing of cattle” (Lee, et al., 2009, p. 15).

As detailed by the authors:

> The approach we used in this study was a combination of classical conditioning and operant conditioning. When an animal approached an exclusion zone it received an audio cue (conditioned stimulus) and if it continued to move forward, it received an electric shock (unconditioned stimulus). The animals responded by turning back or stopping (avoidance) which could be called an operant response. The audio cue was effective at producing an avoidance response only because it was paired with the electric shock. The electric shock acted as a reinforcer because it changed the probability of approaching the exclusion zone and increased avoidance responses in the cattle. (Lee, et al., 2009, p. 21)

In a pilot study, the authors identified an effective audio cue (784 Hz tone) and delivered it with shock (600 V, 250 mW) stimuli by remote control to GPS collars on five heifers to prevent access to an exclusion zone surrounding a feed

\(^1\) The Commonwealth Scientific and Industrial Research Organisation is an Australian federal government agency responsible for scientific research.
trough. The audio cue was administered if the animal entered the exclusion zone and was followed by a shock only if the animal continued forward. Over the course of the four sessions, the number of heifers responding favorably to the audio cue increased by only a factor of 1.66 (from 44% to 73%). In the authors’ words:

“The results of the pilot study provide evidence that the audio cue used in the study was an effective conditioned stimulus when coupled with the electric shock, as shown by the increase in the frequency of desirable responses of the heifers in response to the audio cue over the four test sessions. The behaviourally based application of the audio and shock stimuli appeared to facilitate clear learning in cattle as shown in Fig. 3, with the heifer rapidly learning to associate the audio cue with the shock and respond to the audio cue alone, thus avoiding an electric shock after only one approach. However the presence of the feed trough could also have become a conditioned stimulus as animals consistently received a shock as they approached it.” (Lee, et al., 2009, p. 21)

The study examined whether cattle location could be controlled by an audio-conditioned stimulus, with neither the presence of a visual cue, previously the trough, nor a visual indication of the boundary and/or a boundary that changed weekly. Over the course of 3 weeks, the heifers learned to avoid the electric shock and remained within the virtual fence boundary by audio cue alone. The authors note, “Heifers still learned the association between the audio cue and shock reinforcer as shown by the logistic learning curves and the increase in desirable responses to the audio cue in week 2 compared to week 1” (Lee, et al., 2009, p. 21).

The authors did note large variations in learning speeds between cattle, and temperament may also play a role.

This study provides important explanatory data with respect to associative learning and the role of paired stimuli. This type of data would be difficult, if not impossible, to obtain in studies of wild populations.
**Case 2.2: “Developing an Ethically Acceptable Virtual Fencing System for Sheep”**

Here we shift from cattle to sheep with use of the same research strategy, carried out at the same facility. Marini et al. (2018) used manually controlled collars to apply audio and electrical stimulus to assess the ability of sheep to learn this association for virtual fencing. Their objective was “to develop a training method based on associative learning that enables the animal to recognise a benign cue as a sign of its imminent exposure to the aversive stimulus” (Marini et al., 2018, p. 2).

While the authors demonstrated that “sheep were able to associate an audio cue with an imminent aversive cue and respond to the audio cue alone”, the ability of sheep to learn a virtual fencing system is less definitive, based on the body of evidence. For example, Jouven et al. (2012) found that the virtual fence’s effectiveness decreased with an increase in the number of untrained sheep in the flock or the introduction of an attractant. A study exploring the ability of ewes with lambs to learn a virtual fencing system was stopped after only two days; the authors concluded “it is too challenging to ensure efficient learning and hence, animal welfare cannot be secured” (Brunberg et al., 2016). Given the number of animals in a typical commercial flock, it would be cost prohibitive if not impractical for all animals to wear a device. Furthermore, in contrast to cattle, the animal’s wool may act as an insulator against collar-based electrodes.

In this study, the authors trained 30 four-year-old Merino x Suffolk ewes to associate an audio cue with an electric stimulus:

> “Collars manually controlled by a GPS hand-held unit were used to deliver the audio and electric stimuli cues. For the associative learning, when sheep approached an attractant at a distance of three meters from the trough, an audio cue was applied for one second. If the sheep stopped or changed direction, the audio cue ceased immediately and no electrical stimulus was applied. If the sheep did not respond to the audio cue it was followed by a low-level electrical stimulus. Approaches to the attractant significantly decreased from day one to day two. It took a mean of three pairings of the audio cue and electrical stimulus for a change in behaviour to occur, after which sheep that approached the attractant had a 52% probability of avoiding the electrical stimulus and responding to the audio cue alone. Further research is required to determine whether sheep can be trained to associate an audio cue with a negative stimulus for use in group grazing situations.” (Marini et al., 2018, p. 1)

As was seen with heifers in Case 2.1—and apparently to a more significant degree—the authors recorded large variability between individual animals’ learning ability. As an example, one animal still received an electrical stimulus after eight approaches. The authors speculate that, in some cases, stress may have affected learning ability.

In concluding, the authors make a case for “context,” a critical piece of the realist formula $\text{context} + \text{mechanism} = \text{outcome}$. In their words, “research is also required to determine the impact that an electrical stimulus has on sheep welfare and how sheep in a flock learn to associate audio cues with a negative stimulus for use in virtual fences deployed across a diversity of environmental contexts” (Marini et al., 2018, p. 8).

The mixed results of this study, combined with the failures of related studies on sheep, further confirm species-level variability in the effectiveness of stimuli. We see that this variability also extends to learning at both the species and individual level. With the cited studies, we see the unmistakable influence of context on the intervention’s effectiveness.
BLOCK 3: EARLY-WARNING SYSTEMS

The final set of studies examines virtual fencing as an early-warning system. They offer an opportunity to refine our understanding of virtual fencing mechanisms and to examine the relationships and influences of stakeholders on the effectiveness of an intervention.

Case 3.1: “An Autonomous GPS Geofence Alert System to Curtail Avian Fatalities at Wind Farms”

This study reports on the development of a new biotelemetric technology to minimize the risk of bird-turbine collisions, particularly for threatened and endangered species whose ranges overlap with current and future wind farm sites. Sheppard et al. (2015) developed and applied an autonomous alert system that successfully miniaturizes and integrates virtual geofence capability into solar-powered biotelemetry devices used to track species of large birds currently impacted by wind farms, such as cranes and raptors. These units combine a GPS receiver with a GSM communications system that transmits acquired high-resolution location data via cellular networks in near real-time. Custom sized geofences can be placed around wind farms. When a telemetered bird ingresses one of these virtual boundaries the GPS location fix rate decreases from 15-min to 30 s and an SMS alert is automatically transmitted to a user group within 2-min. When the bird egresses the geofence zone, a second alert is sent and the fix rate returns to 15-min to conserve transmitter energy and data acquisition costs.” (p. 2)

The performance of the devices was successfully field-tested in northern Baja Mexico using a helicopter to mirror the speed, height, and trajectory flight data of nearby California condors. The geofence tags provided highly accurate location data and transmitted SMS alerts within minutes of the helicopter’s crossing a virtual geofence boundary. The researchers did note that:

“Because the GPS fix rate had to first change from the normal 15-min interval to 30 s once the tags crossed the first outer virtual boundary, it took longer to receive an SMS alert after the tags first crossed the outer geofence compared to when they crossed the inner second geofence. Hence, the timing of the initial SMS alert could range from 1 to 15 min depending on where the tag was during its fix cycle.” (Sheppard et al., 2015, p. 5)

As such, the authors recommend that users install at least two geofences around a wind farm. They noted the following additional limitations of this system:

• Its weight would preclude it from being deployed on smaller bird species or bats.
• The solar power system would preclude its use for crepuscular and nocturnal species or during long periods of inclement weather.
The technology necessitates capturing or recapturing birds to place and/or update the biotelemetry systems. The geofence tags currently cost $2,500 each, and data-acquisition fees are $300 per unit per year. Consequently, the cost of telemetering a significant enough sample of other threatened species would have to be weighed against the projected risk of collisions posed by a specific wind farm.

The authors concede that the system may perform poorly if deployed in remote regions where GSM network coverage is likely to be patchy.

A literature-update search provided no evidence that the technology has been operationalized outside of the study area. This study provides further evidence of cost as a significant barrier to effectiveness vis-à-vis implementation. The case also illustrates how technological context(s) can influence the intervention’s effectiveness.

### CASES 3.2 to 3.4: Geofencing Technology to Mitigate Human-Elephant Conflict

**SRI LANKA:**

In June 2019, scientists collared Panu Kota, one of the last two elephants living in the Sinharaja Forest Reserve, a UNESCO World Heritage site (Rodrigo, 2020). Location data is transmitted through the GPS coordinates to wildlife
authorities every 4 hr. If the elephant crosses a virtual fence around the adjacent villages, a message is sent so teams can intervene if the animal remains inside the village. The two male elephants have killed a dozen villagers in past encounters. GPS movement data also allows the Department of Wildlife Conservation not only to validate and make adjustments to their understanding of the elephant’s home range but also to identify areas less often used by elephants for future development and agriculture.

More recently, the National Institute of Fundamental Studies, Sri Lanka, reports on a planned test to determine the effectiveness of animal-borne aversive geofencing devices in managing elephant movement to mitigate human-elephant conflict (Cabral de Mel, 2020). The researchers will test these collars on captive Asian elephants in a linked series of pen trials at Pinnawala Elephant Orphanage in Sri Lanka, focusing on product design, efficacy, and the welfare of elephants. They expect the project will result in an aversive geofencing device for elephants that could be put into larger-scale use in Asia and possibly Africa.

AFRICA:

Geofencing has been employed to control problem elephants in Kenya since 2007. It was initially deployed for a bull elephant that was breaking through the Ol Pejeta Conservancy’s electric fences to raid neighboring maize crops. The nonprofit organization Save the Elephants programmed a virtual fence line of GPS positions into the animal’s tracking collar, creating a geofence around the particular animal (Save the Elephants, n.d.). When the elephant, named Kimani,
broke through, the system generated SMS alerts to wildlife managers. Patrol teams responded to automated alerts from the geofence algorithm; eventually, the behavior was controlled through repeat aversive conditioning (Wall et al., 2014). The organization indicated that the project would be refined and expanded into the Masai Mara in March 2014, but no updates or results have been reported.

This handful of cases illustrates one of the challenges of synthesizing evidence related to interventions to address human-wildlife conflict. As Pullin et al. (2003) demonstrated, many interventions remain unevaluated, and for those where evidence does exist, it’s not often accessible or in a suitable form. Accounts of virtual fencing used for elephant conflict appear in the gray literature and have been highlighted in peer-reviewed sources. Yet no evaluative studies could be found to support these anecdotal accounts. While none of these mini “cases” would survive the quality appraisal of a systematic review, their findings are nonetheless consistent with many of the theories under review. The cases also hint at the role of human influence on the effectiveness of these interventions.

**Case 3.5: “Lions at the Gates: Trans-disciplinary Design of an Early Warning System to Improve Human-Lion Coexistence”**

Between 2016 and 2018, Weise et al. (2019) tested the effectiveness of alerting rural communities to approaching lions to improve the safety of humans and livestock on the northern edge of Botswana’s Okavango Delta. The area’s largely agro-pastoralist households have seen increasing conflict with lions and elephants. According to the study’s authors, “most cattle roam freely across unrestricted communal pastures shared with wildlife, and their management is haphazard, with minimal day-time herding (<10%) and irregular night-time confinement (~40%) in predator-proof enclosures” (Weise et al., 2019, p. 4). While the Department of Wildlife and National Parks compensates livestock owners for lion-related livestock losses at market values, the program has not curtailed persecution and retaliatory killing of lions.

This study includes a critical summary of the researchers’ experiences with “daily online data checks, static risk geofences, subjective evaluation of geofence breaches, and manual alert distribution”. During the 24-month pilot study, the authors alerted communities about geofence breaches by nine lions moving between the delta and adjacent communities. The alert-responsive livestock owners responded mainly by kraaling their cattle and significantly reduced their losses (by $124.61 annually); the losses of the control group and the non-responsive livestock owners stayed high ($317.93 annually). There were challenges, however:

> “Manual alert distribution proved challenging, static geofences did not appropriately reflect human safety or the environment’s strong seasonality that influenced cattle predation risk, and tracking units with on-board alert functions often failed or under-recorded geofence breaches by 27.9%.” (Weise et al., 2019, p. 2)

These challenges informed the trans-disciplinary research design and development of “a versatile, autonomous, Information and Communication Technologies–based (ICT) lion alert system, capable of delivering near real-time alerts through interactive community interfaces on different devices. The evolution of this prototype platform was founded on a co-development strategy with maximum community participation and feedback” (Weise et al., 2019, p. 2).
The authors planned to implement the prototype alert platform in 2019, along with further enhancements of system processes and monitoring of its effectiveness. The Claws Conservancy (2019) reported on its status on its website in June 2019:

“After several field tests, we have finally rolled out our fully Automated Lion Alert System! What makes this system unique is that our colleagues at the University of Siegen created a cloud-based algorithm that can generate a series of virtual fences that send personalized messages to individuals when lions approach within 5 km of their homestead. We have already added over 100 villagers and mapping coordinates for over 30 homesteads and villages. Since our collaring effort in December, we now have 9 collared lions that trigger the alerts across the landscape. The best part is that we can adapt this system as we learn the best options from villager feedback.”

As the alert platform is “neither species- nor context-specific” (Weise et al., 2019), it could find purchase across a number of conservation applications.

The study is fairly unique in that the authors lay out their approach alongside outcomes of a previous attempt. Not only do they explain what worked and what did not, but they also provide supportive evidence to explain why. The result is some of the strongest explanatory evidence to support a number of important theories and to illuminate the gains to be realized from community-centered engagement.

### Case 3.6: Virtual Fencing as a Strategy for Baboon Management

This is a report of a 2016 project carried out by Humane Wildlife Solutions to deploy a virtual fence that mimics natural boundaries and deterrents to reduce conflicts with local chacma baboons in Gordon’s Bay in the Western Cape, South Africa. Other management tools, including monitors and awareness campaigns, had been used, but the researchers saw the potential for these technologically advanced methods to be an efficient, sustainable solution in the Western Cape and elsewhere.

The virtual fence comprised two complementary yet independently operable components: 1) an animal-tracking system including an interconnected network of radio relay stations, real-time monitoring of animals, and a zoned geofence for early warning of approach, and 2) response units made up of a line of speakers running from the edge of the Steenbras Dam downslope along the coast. When the baboons came within 100 m of the virtual fence, the remotely activated speakers played the noises of baboon predators, such as lions and hyenas, as well as unpleasant artificial noises, such as bear bangers and whistles. The intended result was an invisible boundary between the town and the baboon troop’s home range.

In support of the intervention’s effectiveness, the company shared the following testimonial:

“We just “met” the baboons in our virtual fence area. Using stealth we set up the boxes and waited. We used them very successfully. On the first try, they high tailed it after only hearing the lion roar. We continued playing the “distressed animal” and then the “noisy chaos” sounds. We set off two bangers and a whistle.” (Humane Wildlife Solutions, 2020)
While the statement hints at some degree of success, detailed quantitative results of the 6-month trial were largely absent from the report or the associated conference poster. Humane Wildlife Solutions did provide GPS troop-location data prior to the virtual fence, at 3 weeks, and after 3 months that reflected a precipitous decline in troop activity within the exclusion zone.

Humane Wildlife Solutions’ monthly baboon-management reports indicate that the virtual fence is in use in Overstrand and “the primary method of managing the Voëldlip Troop, but paintball markers still continued to be used for backup” (Humane Wildlife Solutions, 2020). More recently, the Overstrand Municipality (2020) posted that Humane Wildlife Solutions’ virtual fence technology will be expanded into Overstrand East and West. Background information shared in the press release provides some additional—yet purely qualitative—insights into program success:

“Since the implementation of the HWS Virtual Fence in mid-February 2020 in Hermanus, there has been a noticeable decrease in the number of occasions that individuals have left the Voëldlip troop to enter town on their own. In addition, the baboons do not travel as far into town as before. Beyond a reduction in human-wildlife conflict, there are other positive environmental benefits of baboons returning to their natural habitats, such as restoring the biodiversity of their ecosystems through seed dispersal for example.” (Overstrand Municipality, 2020)
This study typifies the challenges presented by unpublished industry reports—namely, concealed contexts, oversimplified results, and a bias toward favorable reports. The authors make only a broad generalization about effectiveness and offer little more than hints about mechanisms or context. The continued (and expanding) governmental support for the intervention does, however, lend support for the intervention’s relative success and thus validation of many of the program theories. The influence of education and community-based social marketing can also be teased out of the literature related to the program.
FINDINGS

This review focuses on virtual fencing interventions and on what makes them tick. The review of ground-activated systems led to a deep dive into the internal mechanisms of sensory deterrence, including predator detection and habituation. By shifting to other contexts, namely livestock husbandry and early-warning systems, I could evaluate which aspects of the program theories held up and which changed under a different set of circumstances and goals.

The purpose was not to pass judgment on whether virtual fencing works for human-wildlife conflict. As shown, the evidence of effectiveness is generally mixed. Rather, by drilling down on the mechanisms and then looking across contexts, I try to explain how interventions work, where they can run into difficulties, and how they might be configured better. A summary of the review’s findings regarding the original program theories or hypotheses follows:

Program Theories 1 and 2

Successful virtual fencing interventions have to supply the appropriate type, sequence, and balance of change mechanisms that align with the behavior, physiology, ecology, and legal protections of the intended targets. Unsuccessful interventions follow the application of inappropriate, inadequate, or ill-timed mechanisms.
Theories 1 and 2 were the most general of the program theories; the second is essentially the converse of the first. In simple terms, practitioners must put the appropriate tools in place for the task. The theories hint at the spectrum of mechanisms, from sensory deterrence to associative learning, and the challenge to find and administer the right combination of mechanisms to do the job or, in this respect, to address the conflict. They’re the most general and flexible of the program theories and thus were tested against all of the studies. The key takeaway is that the target species and objectives must drive the selection and configuration of virtual fencing. The perceived effectiveness of an intervention should not bias its selection. Not all interventions will work for all species, even if those interventions have been overwhelmingly effective in other contexts. In the words of Abraham Maslow, “If the only tool you have is a hammer, you tend to see every problem as a nail.”

**Program Theories 3, 4, and 5**

The targeted species’ behavior and physiology heavily influence the effectiveness of virtual fencing interventions. Interventions that initially are easy to implement and deliver well will be difficult to sustain if animals habituate to them. Mixing modalities, multi-stimulus deterrents, and biologically appropriate and/or natural stimuli can slow or prevent habituation.

It’s clear from the first block of studies that ground-activated virtual fencing has a better chance of success if the targeted species’ behavior, ecology and physiology are analyzed up front and incorporated into system design and implementation. Cases 1.1 and 1.2 show the fallibility of any intervention that treats target species as homogenous. Both cases—one purportedly successful, the other not—utilize a commercial off-the-shelf device that was developed in Austria to mitigate vehicular collisions with deer and wild boar. With the exception of the Australian trials, installations remain focused primarily on deer species (IPTE - Traffic Solutions Ltd., 2019). Arguably, the behavior, ecology, and physiology of Tasmanian marsupials will vary considerably from that of ungulates. Yet the researchers installed the devices “as is,” with no documented effort to ensure that the target species were physiologically able to perceive the stimulus and that the stimuli would evoke a desired response, both in the short term and over the long term.

From Coulson and Bender’s (2019) critique of Case 1.1, we know it’s unlikely that Tasmanian marsupials can detect one of the device’s two lights, notably the amber light. Coulson and Bender also suggest that “both stimuli are artificial and lack biological significance, so will be prone to habituation once novelty wanes” (p. 122). They cite Babińska-Werka et al.’s (2015) study (Case 1.4) in support of their assertion that “natural sounds (were) resistant to habituation” (Coulson & Bender, 2019, p. 124)).

Animal behaviors are complex and variable. Such hard and fast rules are rare and often easily challenged by the literature. In many cases, such rules are repeated without invaluable context.

By way of example, in a 2010 review of methods to manage damage by elk, Walter et al. cite four studies in support of a suggestion that the efficacy of frightening devices (for example, conditioning stimuli) “may be improved by simultaneously incorporating a variety of stimuli.” Four years later, their review was the only source for the following recommendation: “To increase their effectiveness, sensory deterrent cues can be used in combination to deter wildlife from utilizing an area” (Jachowski et al., 2013).
The recommendation had been generalized to “wildlife” even though elk or ungulates were the focus of the original four studies. And both statements—“variety of stimuli” and “sensory deterrent cues”—lack specificity. So will all stimuli types deter wildlife so long as they’re used in some combination?

The problem isn’t one of simple linguistic ambiguity; the use of multi-sensory stimuli may not always increase effectiveness, and in some cases, it can possibly decrease effectiveness. For example, Davies et al. (2011) found that spotlights, chili fences, and electric fences were highly effective when used individually to prevent crop-raiding elephants, but when used in combination with noise, their effectiveness was reduced.

Coulson and Bender (2019) cite a variety of ungulate studies to support their assertion that artificial tonal sounds are not effective for reducing roadkill, and that natural sounds are more effective. Here again, the literature is mixed. In Case 1.3, kangaroos responded most aversively to an artificial sound. Playback of natural sounds were less effective (Biedenweg et al., 2011).

Furthermore, predator recognition and threat sensitivity to auditory stimuli vary, even within populations:

“Threat sensitivity has undergone limited testing in the auditory modality, and the relative threat level of auditory cues from different sources is difficult to infer across populations when variables such as background risk and experience are not properly controlled. […]

The ability of organisms to assess the degree of predation risk and respond with appropriate intensity is referred to as the threat sensitivity hypothesis. Predator recognition can occur through innate and learned mechanisms. Organisms can learn to recognize predator cues through direct experience or observation of conspecifics, and may modify perceived predation risk based on experience over time.” (MacLean & Bonter, 2013, p. 1)

Even among natural sounds, the range of threat sensitivity to known predator vocalizations, conspecific alarm calls, and heterospecific alarm calls is highly species dependent:

“Among the auditory cues we hypothesize that a more direct source (vocalizations of known predators) will be perceived as a greater threat. Therefore, we predict that predator vocalizations will be more threatening than conspecific alarm calls, which in turn will be more threatening than heterospecific alarm calls. This relationship, however, does not hold across systems. Barrera et al. found that zenaida doves (Zenaida aurita) increased vigilance and suppressed foraging more in response to predator playbacks than to conspecific wing whistles, a type of alarm signal. Other studies have found this relationship to be completely reversed. Vigilance increased more after playbacks of conspecific alarm calls than after playbacks of predator vocalizations when presented to both American coots (Fulica americana) and yellow-bellied marmots (Marmota flaviventris). Responses to heterospecific alarm calls are less vigorous than responses to conspecific alarm calls for some species pairs, but other species respond equivalently to both heterospecific and conspecific alarm calls.” (MacLean & Bonter, 2013, p. 2)

In short, to maximize the effectiveness of interventions based on virtual fencing, sensory deterre nts must be configured to the target species’ levels of threat sensitivity.

| Program Theory 6 |
Interventions that rely on learning association may be best suited to long-lived, slowly reproducing, social structured, and/or group-living species

This theory is born out of Jachowski et al.’s (2013) proposition that species with “less structured social hierarchies and that produce many offspring and live only a brief period of time are less suitable to manage with virtual fences due to difficulty in capturing, tracking and training many individuals over a relatively short time period” (p. 192). The hypothesis has not been examined in any detail due to the very limited number of trials involving associative learning and the extraordinarily small number of species. And while they hypothesis is likely overstated as written, it may contain an elements of truth based on the interventions reviewed, at least with respect to capturing and tracking.

African elephants live in large tightly knit herds led by a single matriarch. In theory, practitioners need collar only the head cow and she would then serve as a proxy for the herd’s movements. In contrast, female Asian elephants form smaller groups and do not maintain coherent core groups (de Silva & Wittemyer, 2012); this would necessitate deploying a larger number of collars. Males are typically solitary loners. When they do band with other bachelors, the connections are generally loose and transient. This again would necessitate collaring multiple animals or focusing only on problem animals.

Similarly, the social structure of lions would conceivably allow for fewer individuals to be captured and tracked. Weise et al. (2019) collared nine lions (Case 3.5) from different social groups, focusing on males and females with known or suspected conflict histories. The nine animals were responsible for only 31% of the incidents of lion-related livestock predation documented during their study. Untagged (un-collared) lions accounted for the majority (69%) of losses. In addition to the challenges of focal reporting, the authors suggest that tagging only one lion per group can impact the intervention’s effectiveness in so far as population representation is also affected by “lion mortality, changing group compositions and variable cohesiveness, immigration, and emigration” (p. 16).

Program Theory 6 requires further examination, particularly with respect to associative learning. At a minimum, the theory should be restated as “Due to the difficulty and cost associated with capturing, collaring, tracking, and training many individuals, interventions that rely on…”

Program Theory 7

Virtual fences can give communities a feeling of control over natural resources.

This hypothesis has not been examined in any detail, but there are hints of its power. In Case 3.5, Weise et al. (2019) detailed the advantages of directly involving rural communities in the design, development, and testing of their virtual fencing intervention. The community co-designed the user interface for the lion alert system to ensure that it supported diverse ethnicities, languages, socio-economic statuses, cultural traditions, and literacy levels. The co-design workshops, according to the authors,

“...revealed the need for information feedback loops that enable active participation in risk management, thus increasing community ownership. Instead of eroding traditional environmental skills and practices, an ICT-based [information and communication technologies] alert platform provides an interactive avenue for their propagation and inclusion in environmental decision making. Other, maybe less apparent, benefits of a participatory strategy include the community’s perception of “being heard.”” (Weise et al., 2019, p. 15)
The resulting autonomous system allowed for real-time integration of community feedback into alert calculations, increasing community ownership of the process.

**Program Theory 8**

*Human behaviors, attitudes, and actions can dramatically affect the effectiveness of an intervention, even if the actors are not directly involved in the conflict or intervention.*

Conservation practitioners increasingly recognize the importance of social factors in driving human-wildlife conflict (Dickman, 2010; Treves et al., 2010). In this regard, the theory is well supported by the evidence. For example, in Case 3.5, Weise et al. (2019) recognized that their lion alert system “directly hinges upon user responses” (p. 15); thus, they devoted significant design and development resources to improving communication in the autonomous system.

The synthesis also uncovered studies where these drivers had been underestimated or missed. In Case 1.1, the researchers ignored the possible, if not probable, influence of vehicle operators on the intervention’s effectiveness.

Understanding these and other social drivers will be critical to understanding the contexts in which these interventions are applied, the mechanisms by which they work, and the outcomes that they can or will produce.

**Program Theory 9**

*Socio-cultural and technological contexts can heavily influence the effectiveness of virtual fencing applications that depend on user response (for example, early-warning systems).*

This theory builds on the theory before, and here again, it’s well supported by the evidence.

On the whole, virtual fences are cutting edge or novel. When deployed in the developing world, the technological and socio-cultural contexts are often inextricably linked. For example, Weise et al. (2019) recognized that to engage users satisfactorily and sustainably, they had to design their alert system to accommodate for the user community’s “heterogeneity in terms of literacy, attitudes toward modernization, use of communication technology, and language and message style preferences” (p. 16). They acknowledge that “a variety of technological, cultural and individual barriers could inhibit the efficacy of an ICT-based lion alert distribution platform” (p. 15).

Even where technological context is divorced from socio-cultural context, it may factor significantly. As an example, in Case 3.1, the effectiveness of Sheppard et al.’s (2015) intervention is predicated on GSM network coverage, which can be patchy in remote areas where wind farms are typically sited.

**Program Theory 10**

*Integrating education, outreach, and community-based social marketing can increase the effectiveness of virtual fencing.*
Some evidence supports this theory. Certainly, factors described above in relation to Program Theories 7, 8, and, to some extent, 9, lend support for this hypothesis. It appears that a handful of these efforts have paired interventions based on virtual fencing with some form of community-based outreach. The virtual fencing system for baboons detailed in Case 3.6 utilizes social media to update communities (Overstrand Municipality, 2020). Comments on these posts often turn to negative human behaviors driving the conflict—for example, unsecured refuse. In this respect, the social media outreach functioned as simple community-based social marketing.

### Program Theory 11
Virtual fencing that depends on or increases the need for on-the-ground management will be difficult to maintain and sustain.

Based on a scarcity of data, this theory was not tested. Elements of this theory, however, are captured in Program Theory 12, below.

### Program Theory 12
Cost is often a barrier to widespread implementation of virtual fencing, even for interventions that have been proven effective.

This last theory is less a hypothesis than a universal truth. Cost, it appears, is the single most significant barrier to adoption, scalability, and sustainability of virtual fencing. Across the body of evidence, demonstrably effective interventions failed to move from a pilot phase to an experimental one, or from an experimental phase to fully operational. For conservation practitioners, this certainly suggests a less-than-optimistic outlook for what virtual fencing can do for human wildlife conflict.

On the other hand, continued advances in the size, power supply, and cost of GPS animal-tracking systems will hopefully improve the feasibility, scalability, and cost efficiency of interventions. To overcome cost and technological barriers rapidly, there may be no better option than eliminating the need for an animal-mounted collar. And it’s likely that such alternatives will come from disciplines currently outside the spheres of conservation.
RECOMMENDATIONS FOR PRACTITIONERS AND PROGRAM MANAGERS

This synthesis has identified some of the contextual factors that influence the success of virtual fencing interventions. What follows is a modest set of recommendations for possible future research.

A Call for Interdisciplinary Research and Practice

“We are not students of some subject matter, but students of problems. And problems may cut right across the borders of any subject matter or discipline”. (Popper, 1963acad, p. 1)
Interdisciplinary research\(^2\) has the potential to deliver new, innovative, and potentially transformative insights to address increasingly complex and urgent environmental, economic, and social problems (National Academies, 2005), human-wildlife conflict among these. In this context, virtual fencing acts within enormously complex social and ecological systems, which are collectively influenced by myriad forces. A fully descriptive and predictive understanding of the contexts in which these interventions are applied, the mechanisms by which they work, and the outcomes that they can or will produce requires the diverse insights of many disciplines, including but not limited to conservation biology, ethology (animal behavior), cognitive biology, acoustic ecology, engineering, computer science, mathematics, social psychology, and economics.

Facilitating an interdisciplinary exchange of knowledge and experience could stimulate innovative and novel approaches to virtual fencing for human-wildlife conflict. As a jumping off point, I’d suggest convening an interdisciplinary investigative workshop at the National Institute for Mathematical and Biological Synthesis (NIMBioS). The institute supports efforts to focus on major scientific questions at the interface between biology and mathematics and to generate new approaches for addressing them. “Organized by active researchers in academia, government or industry, Innovator Workshops at NIMBioS provide a dynamic, highly interactive forum for the presentation and discussion of cross-disciplinary research at the forefront of biological, mathematical, computational, and social science” (NIMBioS, 2020). Workshops may lead to longer-term working groups, which meet up to three times per year over a 2-year period.

With respect to technology, interdisciplinary teams could help facilitate the design, development, integration, and deployment of more effective, efficient, and resilient virtual fencing components.

**TECHNOLOGY AND THE ART OF THE POSSIBLE**

Costs associated with equipment, data acquisition, deployment, and maintenance have severely hindered adoption and/or scaling of demonstrably effective virtual fencing. Eliminating the need for an animal-mounted collar would go a long way to removing these barriers to entry. Experts best suited to design alternatives to animal-mounted collars will likely come from the fields of engineering, mathematics, signal processing, machine learning, and seismology. As an example, Anastácio et al. (2018) developed and tested a microseismic sensor to locate and track elephants using floor vibration and air-sound signals. Using relatively low-cost accelerometers, the team was able to derive the location of a vibration source mathematically and to identify the source based on its distinct signal patterns. The authors estimate the system would cost 25% less per km than traditional fencing (Anastácio et al., 2018). At least initially, its use would be limited to large-mass animals like elephants.

\(^2\) The National Academies of Sciences defines interdisciplinary research as “a mode of research by teams or individuals that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialized knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or area of research practice” (National Academies, 2005).
Given that elephants utilize vibrational communication, perhaps these signal patterns could prove more reliable than signal patterns derived from the sound of them walking across the ground. Likewise, elephant vibrational alarm calls—if effective in eliciting an anti-predator response—could be incorporated into ground-based sensory deterrents and eliminate some of the need for management intervention. Any combination of these three approaches would eliminate the costs (and risks) associated with elephant-based collars.

**Dissemination and Implementation**

“How do we get ‘what works’ to the people who need it, with greater speed, fidelity, efficiency, quality, and relevant coverage?”

—Implementation Science Program, University of Wisconsin Department of Global Health

In medicine, dissemination and implementation science (DIS) seeks to bridge the gap between evidence-based interventions and their regular use in clinical practice—often called the “know-to-do” gap. DIS researchers not only produce generalizable knowledge but also help find solutions to locally specific problems. Formal DIS programs are embedded within universities and agencies, and the DIS field supports conferences and professional societies as well as a dedicated journal. To date, a parallel, formalized approach for conservation has yet to emerge (Hering, 2018).

DIS in conservation would shorten the time for research findings to be taken up into practice or policy, so impacts and harm to wildlife and human livelihoods could be minimized. Dozens of published theories, frameworks, and models help researchers and practitioners improve the dissemination and implementation of their evidence-based interventions (Dissemination Models, n.d.), and many of these can be adapted for conservation. To accelerate the adoption of DIS, Hering (2018) published a preliminary blueprint to transfer DIS concepts, tools, and approaches from the health to the environmental domains.

**Knowledge Management and Provision**

The threat sensitivity hypothesis holds that organisms assess predation risk and respond to varying degrees based on the perceived threat. Threat sensitivity to auditory cues has undergone only limited testing, and the relative threat level of different types and sources of auditory cues is highly species dependent (MacLean & Bonter, 2013). A body of species-specific stimuli and threat-sensitivity evidence exists, but this information needs to be made more accessible. The availability of this evidence will be critically important to the optimal design and configuration of future virtual fencing applications.

I propose a centralized, open-source library to house not only documentary evidence but also digital acoustic files of animal vocalizations. Ideally, the data could be incorporated into the Cornell Lab of Ornithology’s Macaulay Library, the world’s “premier scientific archive of natural history audio, video, and photographs.” Although the Macaulay Library’s history is grounded in birds, the collection includes mammals, amphibians, and fishes, and preserves data related to each species’ natural history and behavior. The library’s mission is to “facilitate the ability of others to collect and preserve such recordings and to actively promote the use of these recordings for diverse purposes

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3 Macaulay Library: https://www.macaulaylibrary.org/
Community-Based Social Marketing

Integrating communication, education, and community engagement can often strengthen the effectiveness and sustainability of virtual fencing interventions. Such strategies should be informed by behavior-change principles and should incorporate community-based social marketing (CBSM) and risk communication.

Traditional, large-scale, information-based campaigns may raise awareness and change attitudes, but they rarely result in behavior change. An alternative to these traditional approaches, CBSM is based upon research in the social sciences that demonstrates that “behavior change is most effectively achieved through initiatives delivered at the community level which focus on removing barriers to an activity while simultaneously enhancing the activities benefits” (McKenzie-Mohr, n.d.).

CBSM has been successfully applied across a multitude of sustainability-related programs. A meta-analysis of 84 CBSM campaigns to improve global conservation outcomes revealed that all behavioral variables increased 16.1% to 25.0% following social marketing campaigns (Green et al., 2019). The Society for Conservation Biology now has a Conservation Marketing and Engagement Working Group, and “Behavior Change and Social Marketing” is a key topic in the IUCN SSC’s Human Wildlife Conflict Resource Library (IUCN SSC Human-Wildlife Task Force, n.d.).

To increase the effectiveness of virtual fencing, CBSM tools and techniques should be considered during both design and implementation. With respect to the evaluated studies, CBSM could be employed to reduce driver speeds on roads with excessive wildlife mortality, thus giving the animals adequate time to leave the road after the device is activated. Likewise, CBSM could aid in bolstering community-wide adoption of night-kraaling livestock in response to early-warning alerts.
CONCLUSIONS

Realist synthesis shows promise as an important tool for the evaluation and synthesis of conservation evidence. It is particularly well-suited for unpacking the evidence on complex human-wildlife conflict interventions as it looks beyond whether the interventions work to explore how they work in different contexts and why. It is not an approach for novices as it demands reflexivity and flexibility from the reviewer and a high-level of subject-matter expertise. However, realist synthesis’ inclusivity and flexibility offer unique opportunities to develop more insightful and nuanced conclusions about complex interventions than those surfaced by traditional reviews.
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