Received: 12 June 2024 | Revised: 21 April 2025 | Accepted: 8 May 2025

DOI: 10.1111/csp2.70073

CONTRIBUTED PAPER

Conservation Science and Practice
A journal of the Society for Conservation Biology
Open Access

WILEY

Applying knowledge co-production to identify Mojave desert tortoise stressors across time, space, and agency missions

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Funding information
US Department of Defense, Strategic Environmental Research and Development Program, Grant/Award Number: RC22-3182

Abstract

Considerable progress has been made in understanding the effects of stressors on Mojave desert tortoise (*Gopherus agassizii*) populations, yet information about how stressors may vary across jurisdictions, space, and time is lacking. We engaged in knowledge-sharing interviews and a workshop with natural resource managers from multiple jurisdictions located throughout the tortoise's range. This knowledge co-production approach allowed us to learn managers' perceptions of which local to range-wide stressors, synergistic interactions, and important actions impact tortoise populations. We co-produced a list of priority stressors that included Common Raven (*Corvus corax*) predation, roads, climate change/drought, wildfires, and off-highway vehicle routes. Yet, some temporal, spatial, and organizational differences existed in priority stressors. Participants identified important interactions between (1) climate change/drought, invasive plants, and wildfire and (2) human presence and predation from human-subsidized predators. Key actions for tortoise recovery included invasive plant removal, education and outreach, surveys, and habitat restoration, which did not always address prioritized stressors, partially because of logistical and monetary constraints. A co-production approach was vital to learning which stressors managers perceived as most important and varying over space and time, and the logistical constraints associated with managing these stressors.

KEYWORDS

climate change, cross-jurisdictional management, drought, *Gopherus agassizii*, non-native plants, off-highway vehicles, predation, roads, threats, wildfire

1 | INTRODUCTION

The conservation of threatened, endangered, and sensitive (TES) species has been most successful for species facing easily identifiable and remediable stressors (Abbitt & Scott, 2001; Doremus & Pagel, 2001). In contrast, species facing multiple synergistic stressors experience greater obstacles to recovery (Averill-Murray et al., 2012; Darst et al., 2013; Scott et al., 2006). Recovery of TES populations is also challenging for natural resource managers ("managers" refers broadly to on-the-ground experts involved in recovery efforts, biological surveys, and research, e.g., practitioners, biologists, stewards) due to competing objectives between conservation goals and human land uses, especially in the face of rapidly changing environmental conditions (Averill-Murray et al., 2012; Hodgson et al., 2009; Redpath et al., 2013). These management challenges can be particularly acute when tradeoffs exist between essential land uses (e.g., military training) and protected resources (e.g., TES species) (Stein et al., 2008). Given that TES species often cross jurisdictional boundaries, conservation strategies that include collaborations among multiple agencies can increase understanding of range-wide and site-specific concerns and facilitate innovative approaches for recovery (Averill-Murray et al., 2012).

The Mojave desert tortoise (*Gopherus agassizii*) (hereafter "tortoise") is one such cross-jurisdictional species. It was federally listed as 'threatened' under the Endangered Species Act (ESA; USFWS, 2022) over three decades ago and listed as endangered by the state of California in 2024. Tortoise management is complex because populations occur throughout the Mojave Desert ecoregion (California, Nevada, Arizona, Utah) on lands managed by federal and non-federal jurisdictions, including the Department of Defense (DoD); Department of Energy (DOE); multiple agencies within the U.S. Department of Interior (DOI): Bureau of Land Management (BLM), Bureau of Reclamation (BOR), National Park Service (NPS), U.S. Fish and Wildlife Service (USFWS); tribal nations; and state, county, and local governmental agencies (Figure 1). These agencies have different missions, such as the DoD, whose mission is to 'provide the military forces needed to deter war and ensure our nation's national security' (DoD, 2025), and NPS (2023), whose mission is to 'preserve unimpaired the natural and cultural resources and values of the National Park System for the enjoyment, education, and inspiration of this and future generations' (NPS, 2025). Therefore, they may experience different management approaches, challenges, and priority stressors that tortoises encounter. The DoD is an important steward because large areas of tortoise habitat are located within and adjacent to DoD installations (Figure 1; USFWS, 2011, Carter et al., 2020). Despite substantial management and research investments in tortoise conservation by these agencies, the species remains in decline across much of its range (Allison & McLuckie, 2018; Kissel et al., 2023; Zylstra et al., 2019). Considering these challenges, the DoD and the DOI developed an action plan under the Recovery and Sustainment Partnership initiative (DoD and DOI, 2018, 2019; National Fish and Wildlife Foundation, 2022) to accelerate tortoise recovery while reducing the regulatory burden on the DoD.

Dozens of studies have identified multiple potential stressors on tortoise persistence and recovery (e.g., Averill-Murray et al., 2012; Berry et al., 2020; Darst et al., 2013; USFWS, 2022). Stressors include, but are not limited to, invasive plant species (e.g., Drake et al., 2016), low-quality forage and shelter options (e.g., Dickson et al., 2019), subsidized predators (e.g., predator species that benefit from human resource subsidies, such as food waste; Esque et al., 2010, Cypher et al., 2018, Holcomb et al., 2021), road mortality (e.g., Averill-Murray & Allison, 2023; Peaden et al., 2017), extended drought conditions under a changing climate (e.g., Freilich et al., 2000; Longshore et al., 2003; Lovich et al., 2014; Mitchell et al., 2021), disease and bacterial infection (e.g., Weitzman et al., 2017), environmental toxins (e.g., Chaffee & Berry, 2006; Cohn et al., 2021), wildfire (e.g., Hegeman et al., 2014; Kissel et al., 2023), and other anthropogenic factors (e.g., Carter et al., 2020; Tuma et al., 2016). To avoid potentially research-specific jargon (Cash et al., 2003), we use 'stressor' to refer to any factor that negatively impacts tortoise populations.

Informed by an existing population viability analysis and tortoise biologists' expert opinion on stressor importance, Darst et al. (2013) developed a comprehensive model of the relative importance of stressors based on the risk to tortoise populations, synergistic effects of multiple stressors, and effectiveness of various management actions to support species recovery. More specifically, the Darst et al. (2013) model was used to develop a spatial decision-support tool to help prioritize recovery actions that would provide the greatest benefits to tortoise populations (USFWS, 2022). This tool was leveraged in regional recovery action plans to prioritize local recovery actions (USFWS, 2014a, 2014b, 2014c). Although these plans show regional variation in stressor priorities and represent valuable snapshots of stressor and recovery action priorities in 2014, the underlying models were not publicly available and are inaccessible today. In addition, the study did not include manager perceptions of priority stressors, temporal variation in stressors, or disparate impacts from agency mission and focus. The development of new tools that reflect current priorities is needed to keep pace with scientific knowledge, evolving stressors, and lessons learned from recovery action implementation.

Researchers are not the only authoritative knowledge source (O'Connor et al., 2021) and managers can provide valuable knowledge about stressors and recovery action implementation from their on-the-ground experiences. This insight can help inform the development of these new tools (Nel et al., 2016). Although many types of knowledge are invaluable for conservation (Grimm et al., 2024), we focus on Academic Ecological Knowledge, Local Ecological Knowledge, and managerial

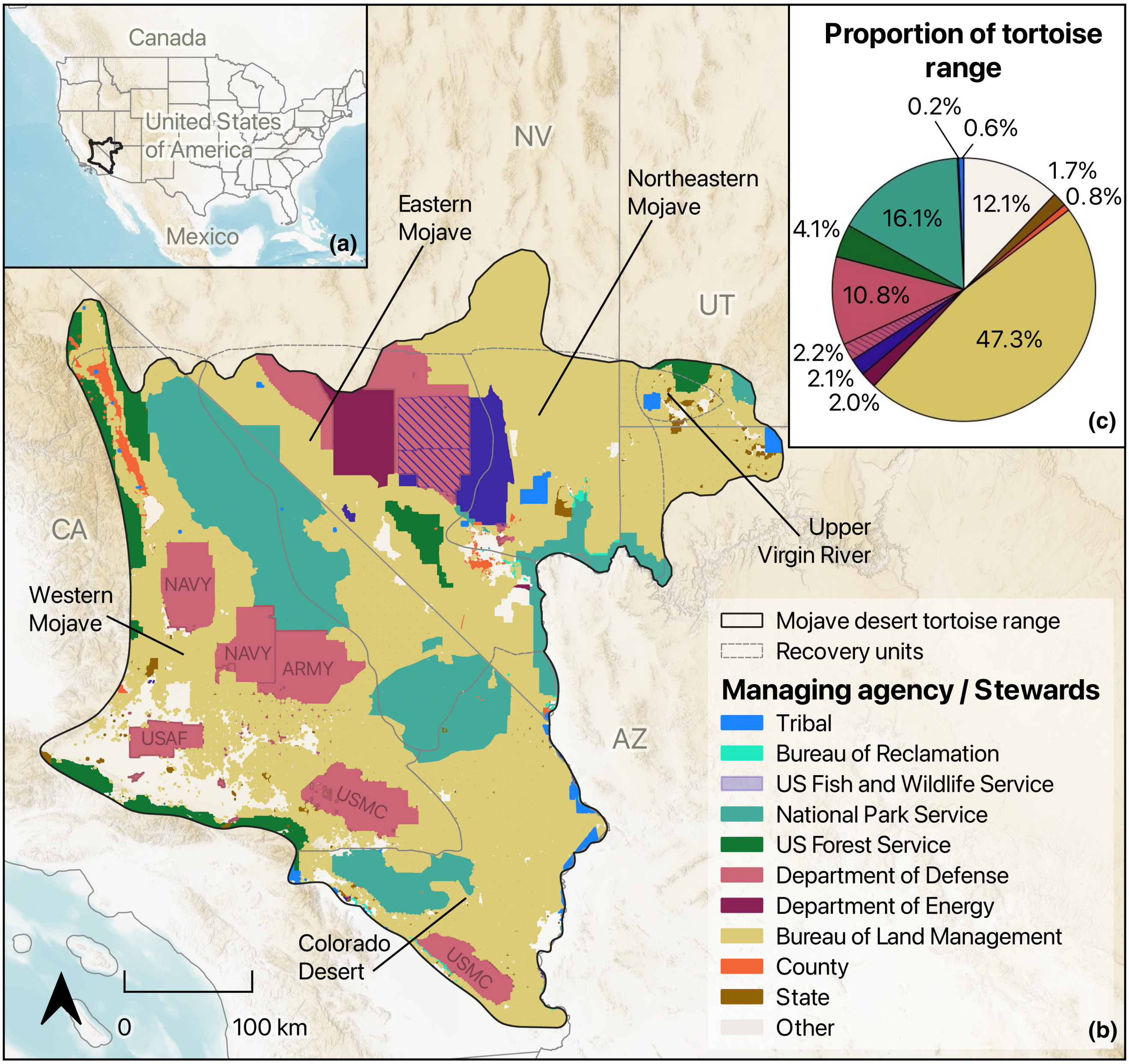

FIGURE 1 Land management and stewardship across (a) the approximate range of the Mojave desert tortoise (*Gopherus agassizii*) in the southwestern United States. (b) Land ownership data from the Bureau of Land Management (2024) and tortoise population 'recovery units' from the species Recovery Plan (USFWS 2011) are overlaid on top of the species' range. Imperfect overlap between these units and the species' range reflects differences between the species' approximate distributional limits and the recovery units from the most recent recovery plan) (USFWS 2011). (c) Proportion of the total Mojave desert tortoise range area managed by each agency/entity. The pink and purple cross-hatching indicates areas where the DoD and USFWS co-manage land.

knowledge because these are common among managers across these jurisdictions. In addition to science learned in academic settings, managers may hold local ecological knowledge, or "knowledge, practices, and beliefs gained through extensive personal observation of, and interaction with local ecosystems" (Charnley et al. 2008). Managers' on-the-ground interactions with and experiences of the ecosystem and tortoises provide local nuance and context. Managers may also hold important knowledge about the decision context, mechanisms for action, current priorities, and strategic use of information (Beier et al., 2017; O'Connor et al., 2021). By working with managers, we increase the potential that they see the research as salient, credible, and legitimate (Cash et al., 2003; Cook et al., 2013), and in turn, be more likely to include it in management and decision-making (Cook et al., 2013).

Therefore, we saw an opportunity to use knowledge co-production to learn from managers from multiple jurisdictions across the Mojave Desert. Knowledge co-production is "the collaborative process of bringing a plurality of knowledge sources and types together to address a defined problem and build an integrated or systems-oriented understanding of that problem" (Armitage et al., 2011). It can address management challenges, particularly in situations with high spatial, temporal, jurisdictional, and context complexities (Beier et al., 2017), and allows science producers and users to share their knowledge, learn from each other, and build relationships to collaboratively develop solutions. These efforts necessitate early, iterative, and collaborative engagement of science users and producers throughout the process of research development, execution, and application (Beier et al., 2017; Dilling & Lemos, 2011; O'Connor et al., 2021).

We used a co-production approach to answer the following questions: (1) which stressors do managers believe have the greatest impact on tortoise populations, locally and range-wide; (2) if and how top stressors vary spatially and temporally; (3) what important synergistic interactions between stressors exist; and (4) what management actions are used to minimize the effects of stressors, and what constrains these actions? Our research findings will provide an updated technical snapshot of priority stressors identified by the management community and will inform the co-development of tools to aid in decision support and scenario planning that are more likely to be salient for managers (Cash et al., 2003).

2 | METHODS

2.1 | Data collection and analysis: A knowledge co-production approach

This article details the initial phases of a larger 5-year project that employs a knowledge co-production approach throughout the entire project arc (e.g., research design, needs identification, testing and feedback on tools; Data S1) and includes researchers (present authors) and managers at federal, state, county, and tribal jurisdictions involved with tortoise management. We approached the knowledge co-production process as a continuum of activities and stages in which to participate, in turn, strengthening the overall outcomes and partner relationships (Colavito et al., 2019; Djenontin & Meadow, 2018; Grimm et al., 2022). To increase understanding of tortoise stressors and management approaches, we focused on activities that fostered multidirectional knowledge exchange, understanding managers' needs, co-development of research outputs, and inclusion of diverse partnerships (Beier et al., 2017; Cash et al., 2003; Djenontin & Meadow, 2018; Enquist et al., 2017; Grimm et al., 2022). These activities were built into (1) knowledge-sharing interviews and (2) a knowledge-sharing workshop where participants validated, revised, and added to the list of stressors and management actions identified in interviews. The workshop was designed to foster knowledge exchange among all stakeholders by providing opportunities to learn how others applied science and management approaches (O'Connor et al., 2019).

2.1.1 | Ethics approval and guidelines

Conservation Science Partners (CSP) does not have an IRB or ethics committee, so ethics approval is not required. However, the lead author has completed the Collaborative Institutional Training Initiative (CITI Program) Human Subject Research Training for Social, Behavioral, Education Researchers and is up to date on their certification. We followed CITI's best practices for ethical human subjects' research in all steps, including research design, interview guide development, and data collection and storage methods (e.g., informed consent, allowing for participants to skip questions, removing identifiable information). In the email requesting an interview, the lead author provided potential participants with information to help them make their decision (e.g., length, study purpose, confidentiality, how data will be used). Before an interview commenced, the lead author asked if questions remained before deciding to participate, and then confirmed their consent to both participate and be audio-recorded. A similar process was followed with the workshop. Data was secured on CSP's secure storage drive in a locked folder only accessible to CSP employees involved with the project and who had permission. The list of interviewee names and assigned codes was kept separate from the recordings and transcripts that were de-identified and contained the code. The lead researcher made sure all staff were aware of the ethics protocol.

2.1.2 | Interviews

We sought to interview people working at federal, state, county, or tribal agencies involved in management decisions impacting the tortoise (Data S1), including those at the regional level or a specific site (e.g., military installation, national park). To identify interviewees who represented a reasonable sample of the jurisdictions and sites on the landscape, we opportunistically engaged points-of-contact at multiple agencies, and then employed 'snowball sampling' (Bernard, 2006).

We conducted one-hour, semi-structured interviews over virtual conferencing platforms or telephone during January–July 2023. For this article, we focus on interview questions (Data S1) about experience and background; top two to three factors driving tortoise populations in the present, past, and future where they worked; and tortoise recovery actions and challenges. Questions were based on existing literature, knowledge gaps in tortoise research, and discussions with partners who study or manage tortoises. We recorded the interviews, uploaded transcripts into NVivo Qualitative Analysis Software (V.12), and organized quotes into codes representing recurring themes (Bernard, 2006; Miles & Huberman, 1994). A participant code (Data S1) indicates their agency and interviewee number (e.g., DoD1 = Department of Defense 1).

We tabulated the number of people mentioning each stressor to determine which stressors were most frequently highlighted by all participants, and across specific regions and organizations. To capture the diversity of missions and goals, we categorized interviewees by their agency's focus (e.g., NPS respondent: [*recreation/wildlife*]) and whether they worked at a specific site [*site*] or regional office/state department [*general*], leading to five categories: *defense/security* (*site*), *multiuse* (*general*),

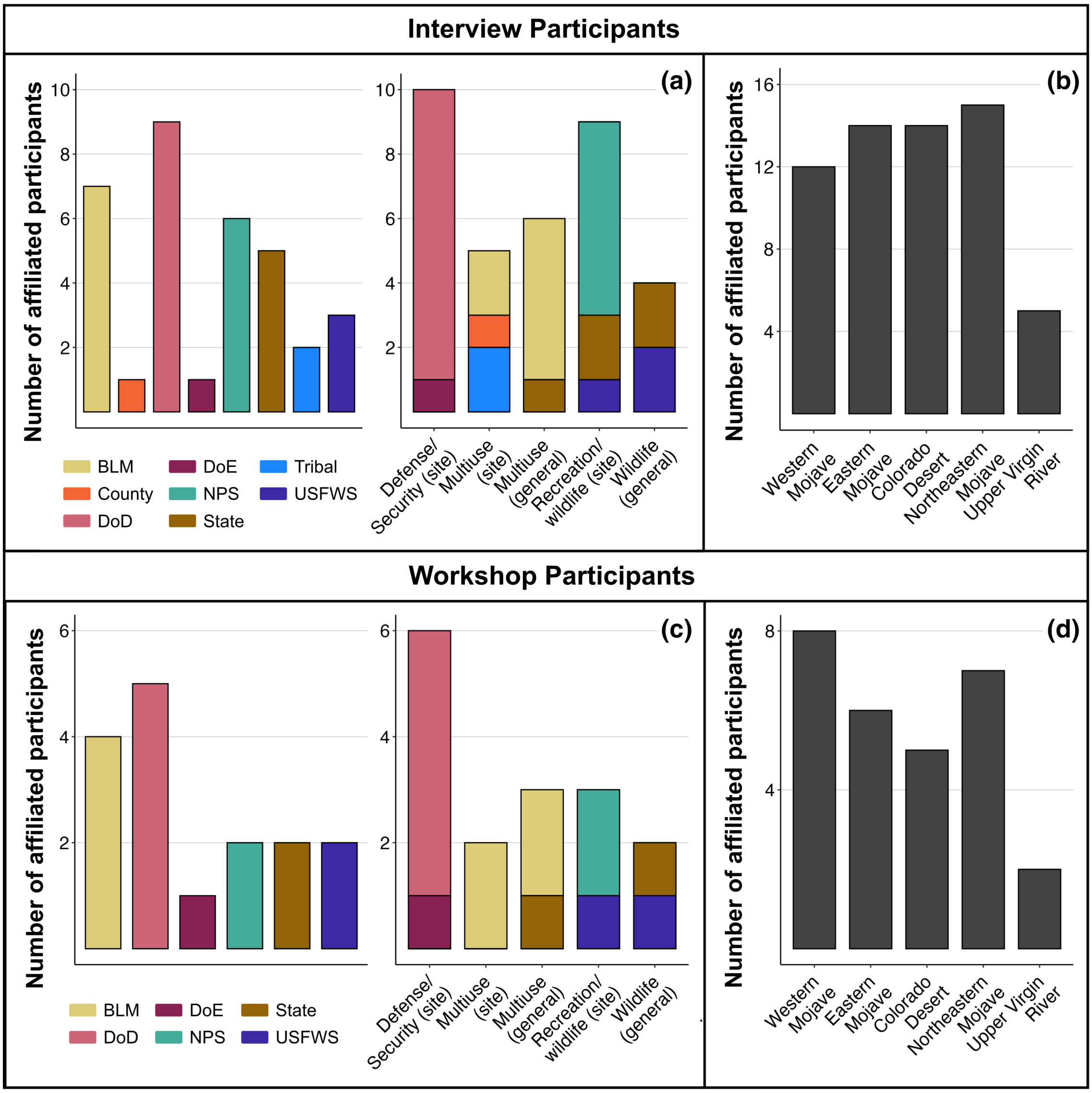

FIGURE 2 (a) Number of interviewees who participated in knowledge co-production efforts related to the management of the Mojave desert tortoise (*Gopherus agassizii*) as categorized by jurisdiction (left) and agency mission categories (right). (b) Number of interviewees working in each US Fish and Wildlife Service recovery unit (USFWS 2011). Individuals can work in more than one recovery unit, and the total number exceeds the number of interviewees. (c) Number of workshop attendees who participated in knowledge co-production efforts related to the management of the Mojave desert tortoise (*Gopherus agassizii*) as categorized by jurisdiction (left) and agency mission categories (right). (d) Number of workshop participants working in each US Fish and Wildlife Service recovery unit (USFWS 2011). Individuals can work in more than one recovery unit, and the total number exceeds the number of interviewees.

multiuse (*site*), *recreation/wildlife* (*site*), and *wildlife* (*general*). Categorization of agencies into these groups is illustrated in Figure 2a. These categories allowed us to explore potential differences between respondents at a specific site, whose views may be based on site-specific observations, and those at the state or regional level. The distinction between sites and a broader regional or agency focus is especially important as we asked respondents to reflect on stressor priorities where they worked. To evaluate spatial differences, we classified interviewees by the tortoise population recovery unit(s) (USFWS, 2011) where they worked—Western Mojave, Eastern Mojave, Northeastern Mojave, Colorado Desert, and Upper Virgin River Recovery Units, which were created to plan population recovery under the ESA.

We interviewed 34 individuals from a diversity of regions, states, and jurisdictions overlapping the tortoise's range (Figure 2a; answers from two individuals who participated in a joint interview were combined for a site-specific response). Most interviewees were federal employees with the DoD; other federal agencies included the BLM, NPS, USFWS, and DOE. Six state or county-level managers and two non-Indigenous resource managers employed by and representing, with permission, a tribal reservation also participated (Figure 2a). Respondents were primarily categorized as *defense/security* (*site*) or *recreation/wildlife* (*site*) (Figure 2a). Many respondents worked across multiple recovery units (Figure 2b), and the stressors that they listed could be relevant to one, but not necessarily all, recovery units with which they are affiliated. The workshop provided an opportunity for respondents to clarify regional details.

2.1.3 | Workshop

To continue learning from managers, revise our assessments based on their feedback, and provide opportunities for managers to learn from each other and develop/strengthen partnerships, we invited interviewees to a virtual knowledge co-production workshop held in September 2023. Details of the workshop structure, breakout questions, and methods for creating an open forum to share views are detailed in Data S1. Major goals of the workshop were to discuss the interview results; have participants validate our interview findings (i.e., member check, Lincoln & Guba, 1985) and share new information; revise our priority stressor list and management actions if needed; and identify similarities and differences in the top-priority stressors affecting tortoise populations at local and range-wide scales. Facilitators took detailed notes of discussions, and the workshop was audio-recorded and later transcribed. To identify key findings, we categorized participant responses contained in the workshop transcripts and facilitator notes into existing or emerging themes.

Although the workshop was heavily dominated by federal employees, with only two others from state agencies (Figure 2c), federal participants worked in different recovery units (Figure 2d) and for agencies with diverse missions. Therefore, they represented a wide breadth of management priorities and decisions, which lend themselves to multi-directional learning important in knowledge co-production.

3 | RESULTS

3.1 | Stressors

3.1.1 | Managers' priority stressors

Overall, there was general agreement among respondents as to which priority stressors impacted the tortoise range-wide currently, previously, and potentially in the future (Figure 3). Most respondents ($n = 18$) indicated that predation by Common Ravens (*Corvus corax*), a native species protected under the Migratory Bird Treaty Act of 1918, is a prevalent current stressor: "*If ravens have access to resources … that boosts their population numbers and allows them to expand their range and … ability to depredate more tortoises. And they're very effective at it*" (NPS1). Some interviewees suggested that raven abundance was not always due to actions under their control but instead activities (e.g., lack of trash management) on neighboring land managed by other jurisdictions. The other most frequently mentioned stressors were roads ($n = 15$), climate change/drought ($n = 11$), off-highway vehicles (OHV) ($n = 11$), and non-native plants ($n = 9$). After seeing these results, workshop participants agreed we had correctly captured their priority stressors. However, although wildfire was the ninth most frequently mentioned stressor in interviews, workshop participants concluded that it was one of the most important stressors because of its strong, indirect, and synergistic effects.

Interviewees indicated that these current priority stressors, especially ravens, were the top stressors impacting tortoises in the past (Figure 3). However, several respondents stated that the impact of ravens was lessening, partially due to USFWS actions, such as egg oiling (i.e., applying oil to eggs to prevent hatching). NPS5 explained, "*Now we see raven densities well below the threshold* [*necessary for tortoise population viability*]", but also noted, "*We still see the issue … mainly because of … restrictions and our ability to access raven nests*". Paved roads remained the second most mentioned past priority

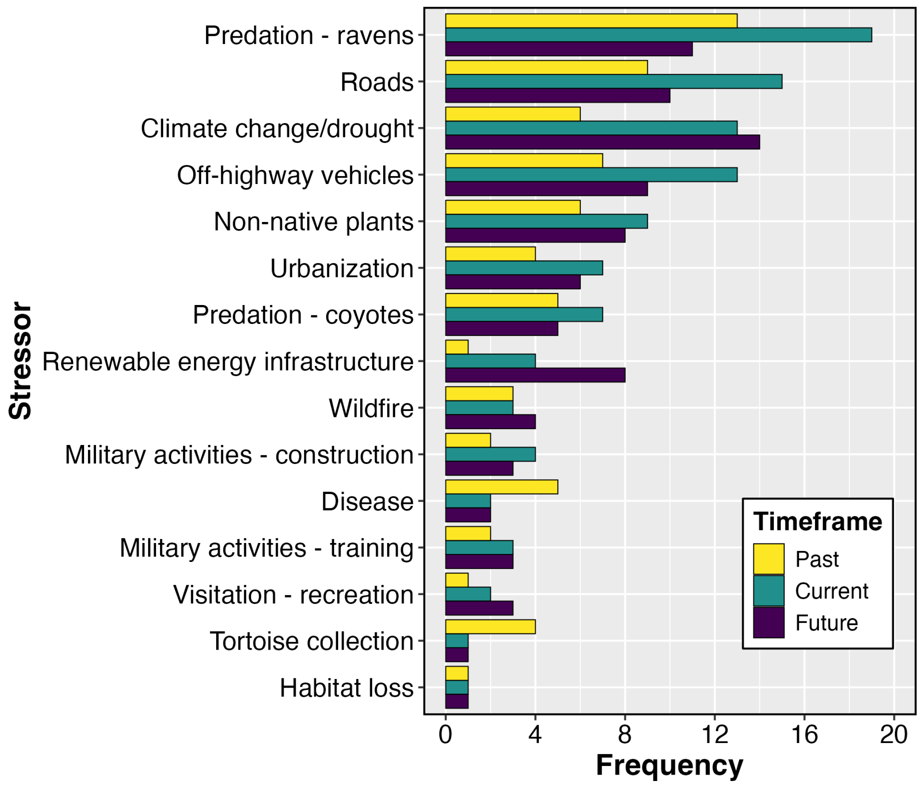

FIGURE 3 The frequency of interviewees ($n = 34$) mentioning individual stressors as one of the top three factors impacting Mojave desert tortoise (*Gopherus agassizii*) populations in past, current, and future timeframes. Stressors are ordered by overall frequency (summed across the three timeframes) from high to low; eight stressors were mentioned only once across all timeframes and not included here. Some individuals had recently started their positions and had varying levels of insight about past stressors, depending on the institutional knowledge that had been shared with them. Thus, comparisons between current and past stressors should be made cautiously.

stressor, followed by OHV routes (third) and climate change/drought and non-native plants (tied fourth). It is worth noting that due to different lengths in these positions, as well as potential previous experience in other tortoise-related positions not captured in the interviews, individuals had varying levels of insight about past stressors; therefore, comparisons between current and past stressors should be made cautiously.

Most interviewees anticipated that the current priority stressors (raven predation, paved roads, OHV routes) would remain significant; however, due to current and predicted precipitation patterns, climate change/drought was mentioned most frequently as a top future stressor. T2 shared, "*With the ongoing climate change epidemic … we could see … excessive heat … becoming a main factor for the decline of the desert tortoise population*". Several respondents anticipated renewable energy infrastructure to be a greater stressor in the future as plans for nearby solar installations progress, in turn, resulting in habitat loss and decreased habitat connectivity, among other consequences. DoD9 expressed, "*Alternative energy projects are now manifesting throughout much of the Mojave … they are essentially a different form of habitat conversion … I think that's going to continue … for a while*". In the workshop, participants further emphasized that increased urban growth, climate change/drought, and renewable energy development would be greater stressors to tortoises moving forward.

3.1.2 | Stressors by recovery unit

Despite general trends in responses about range-wide stressors, participants expressed that local and spatial nuances due to natural variation (e.g., precipitation patterns) and differing anthropogenic pressures (e.g., urbanization) can get lost when lumping areas together or scaling up. Although interviewees in the Colorado Desert and Western Mojave Units most often mentioned predation by ravens (Figure 4), other stressors were highlighted as often, if not more frequently, by respondents associated with other recovery units. For example, managers working in the Eastern Mojave Unit identified roads as a priority stressor as frequently as ravens. Roads, climate change/drought, OHVs, and ravens were equally mentioned as priority stressors in the Northeastern Mojave Unit. STC2, who worked in the Eastern and Northeastern Mojave Units, explained that they had far fewer raven problems than California. In the Upper Virgin River Unit, especially around the rapidly expanding city of St. George, respondents more frequently identified roads as the current top stressor: "*We have the potential northern corridor that's going to put … a road through … one of the densest* [*tortoise population*] *areas within the Upper Virgin River recovery unit*" (STC1).

Renewable energy infrastructure emerged as one of the most important future stressors for individuals in the

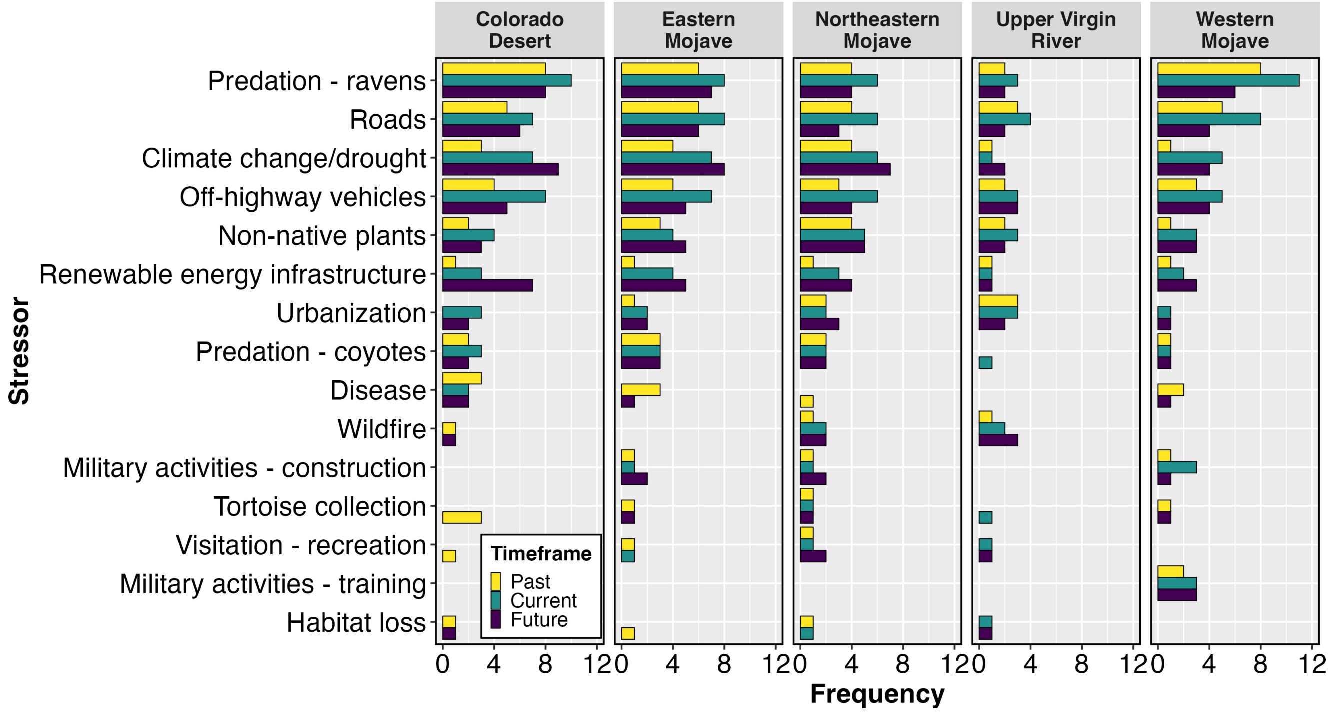

FIGURE 4 The frequency of interviewees from different US Fish and Wildlife Service recovery units who identified individual stressors as one of the top three factors influencing Mojave desert tortoise (*Gopherus agassizii*) populations in past, current, and future timeframes. Panels are organized by recovery unit from west to east, approximately: The Western Mojave ($n = 12$), Colorado Desert ($n = 14$), Eastern Mojave ($n = 14$), Northeastern Mojave ($n = 15$), and Upper Virgin River ($n = 5$) recovery units (USFWS 2011). Stressors are ordered by overall frequency from high to low; eight stressors that were only mentioned once were not included here. Given that some individuals worked across several recovery units, we categorized their responses in all units where they worked.

Colorado Desert Unit, with only climate change/drought and ravens mentioned by more respondents. In the Northeastern and Eastern Units, renewable energy infrastructure was highlighted in similar frequencies as several other priority stressors (non-native plants, OHV routes, roads). BLM1 elaborated: "*We've got … 10 or 12 active projects right now, which … if they all were built, you're talking about potentially up to 50,000 acres of occupied tortoise habitat destroyed*". However, STC6 anticipated that the creation of such installations would be less of a future concern in California once the state reaches its renewable energy goals.

After reviewing the interview results, workshop participants further discussed geographic variation. Region-specific priority stressors included urban growth around Las Vegas, NV (Eastern Mojave Desert Unit) and St. George, UT (Upper Virgin River Unit), raven predation in the Western Mojave Desert Unit, and renewable energy development in California and southern Nevada. For ravens specifically, participants emphasized that the problem differs across spatial scales (e.g., site, region). For example, areas with anthropogenic infrastructure (e.g., transmission lines suitable for nesting sites) can increase raven abundance, while management efforts can decrease it.

3.1.3 | Stressors by organizational focus

Stressor importance varied by organizational focus (Figure 5). More *multiuse* (*general*) respondents identified OHVs as a current stressor than they did other stressors, and renewable energy, climate/drought, and OHVs as future priority stressors. In contrast, *recreation/wildlife* (*site*) respondents emphasized that roads dissecting recreation/wildlife areas were greater current and future stressors. NPS3 explained that road mortality was a huge concern, especially given the agency's focus on visitor values (e.g., recreation, scenery): "*Fencing in a national park is … something we don't like to do. You drive along the roads enjoying your park and you see a fence out there*".

For *defense/security* respondents, although ravens remained the top priority stressor, along with climate change/drought, they frequently mentioned coyotes (*Canis latrans*) and military activities (construction, training). Some construction was not anticipated to remain a significant future stressor due to the near completion of work. In contrast, ravens were expected to continue posing problems because many installations house military personnel and/or are adjacent to public lands or towns, all of which can generate raven attractants (e.g., trash).

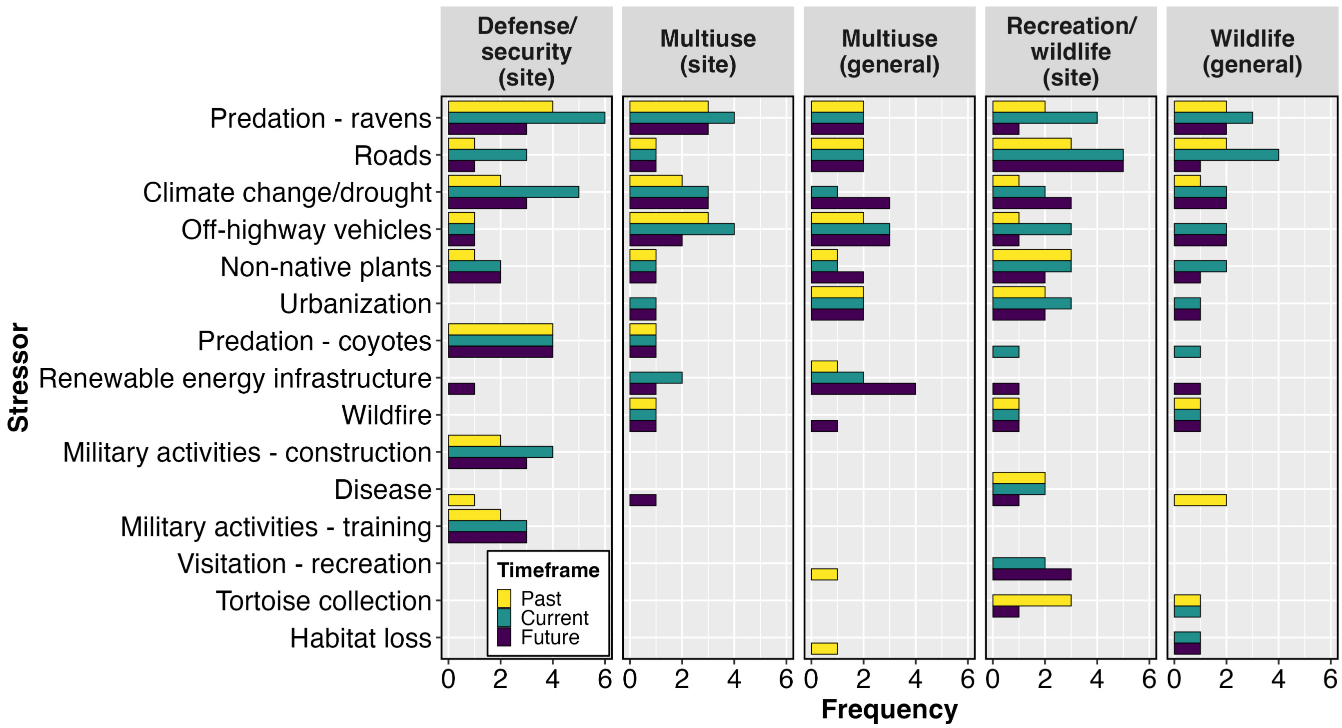

FIGURE 5 The frequency of interviewees from different agency foci who mentioned individual stressors as one of the top three factors influencing Mojave desert tortoise (*Gopherus agassizii*) populations in past, current, and future timeframes. Panels are organized by agency focus: Individuals from jurisdictions focused on defense or security who are located at a specific installation ("defense/security [site]"; $n = 10$), individuals from jurisdictions focused on multiple land uses who were not located at a specific site ("Multiuse [general]"; $n = 6$), individuals from jurisdictions focused on multiple land uses who were located at a specific site ("Multiuse [site]"; $n = 5$), individuals from jurisdictions focused on recreation and wildlife who were located at a specific site ("Recreation/wildlife [site]"; $n = 9$), and individuals from jurisdictions focused on wildlife not located at a specific site ("Wildlife [general]"; $n = 4$). Stressors are ordered by overall frequency from high to low; eight stressors that were only mentioned once were not included here.

Not all *defense/security* respondents indicated that military training activities were a priority stressor because the type (e.g., test flights vs. ground training missions) and location of military activity varied across installations. Size of an installation also played a role, with larger installations able to concentrate training in certain areas. DoD8 explained that their ground training, although intense, occurred in degraded, flat areas, and many of the tortoises had moved into the foothills. However, some respondents expressed concern that the defense/security mission is prioritized over the tortoise. DoD6 shared that in a recent training, troops "*didn't stay within* [*the established*] *lines* … [*they said*] '*this looks exactly like what we have to go to overseas*.' *It's like*, '*No, you guys need to stay within these areas because they're already disturbed*'".

Several *defense/security* respondents believed that the restricted nature of their sites protected the tortoise, whereas NPS, BLM, and USFWS allow public access on their lands. Therefore, these interviewees viewed OHV disturbance as less of a concern. In addition, solar projects cannot be constructed on bases, so those were not seen as a priority stressor. DoD5 explained, "*The rest of the range is basically* [*a*] *protected buffer and it's obviously protected from the use of people, off-road vehicles, development, and everything else. So … while we don't do a lot* [*for tortoise recovery*], *that is a lot in itself*".

3.1.4 | Synergistic stressors

Both interview and workshop participants emphasized the need to consider and manage the synergistic effects of stressors, especially (1) human presence and raven abundance (e.g., trash attracting ravens); and (2) climate change/drought that enables non-native plant species to flourish and increase fuel loads for wildfires, which in turn increases invasive plant species (Figure 6). When STC1 started their position, "*wildfires were small because we didn't have the fuel between the shrubs that would carry the fires … because of climate change, now we have hotter conditions and we're more susceptible*". There were also concerns that non-native plant species (e.g., Sahara mustard [*Brassica tournefortii*], red brome [*Bromus rubens*],

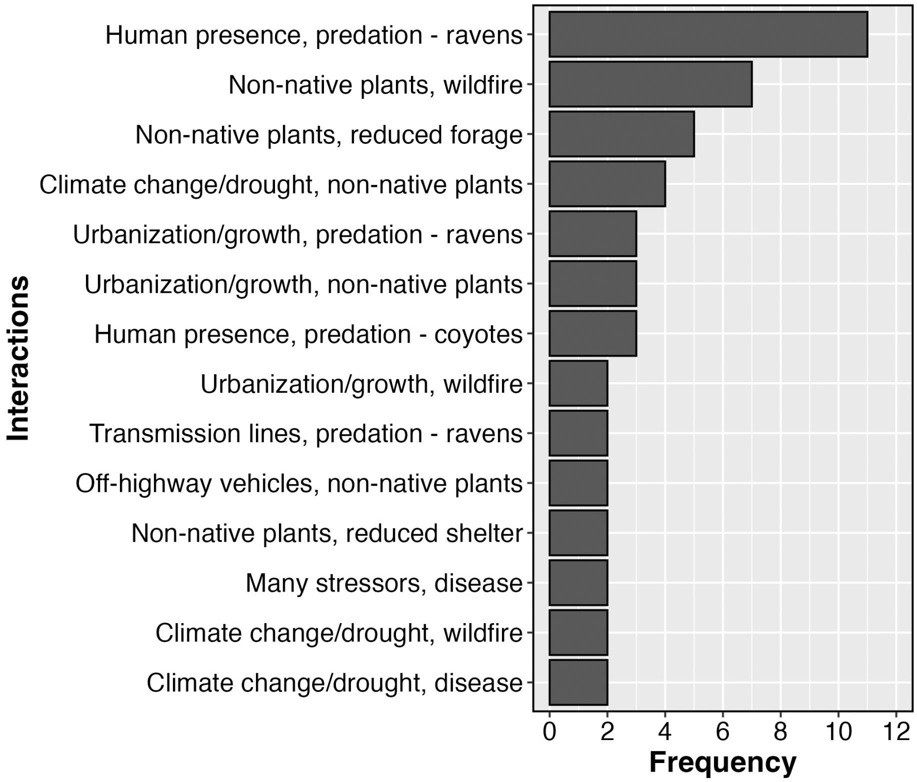

FIGURE 6 The frequency with which interviewees mentioned interactions between stressors (i.e., synergies) as important factors influencing Mojave desert tortoise (*Gopherus agassizii*) populations. Categories are ordered by overall frequency from high to low. Interactions mentioned only once were not included.

cheatgrass [*Bromus tectorum*]) were outcompeting native forage, decreasing available food sources for tortoises, and negatively impacting survival rates.

3.2 | Management actions

Interviewees used a wide range of actions to minimize the effects of priority stressors and support tortoise recovery, which can broadly be grouped into education/outreach, biological surveys, policy and compliance, and on-the-ground management. In general, management actions did not correspond with specific recovery units or agency missions, except *multiuse* (*general*), which primarily implemented habitat restoration. Workshop participants generally agreed that the actions identified from interviews included the ones they used. The workshop also provided an opportunity for them to learn new approaches from each other, some of whom planned to later connect. However, participants suggested that some management actions are used more frequently and/or are more important than the summary frequencies revealed (e.g., law enforcement). The workshop allowed participants to further discuss constraints that limit actions they can take (e.g., cost, staffing capacity, logistical constraints, difficulties managing across jurisdictions, NEPA compliance issues, permit acquisition).

Despite these constraints, on-the-ground recovery actions encompassed numerous approaches, such as restoration, fencing, and raven control. One of the most common actions involved invasive species removal and native plant restoration, which can lead to broader habitat restoration and resulting benefits: "G*etting rid of … non-natives can affect …* [*the*] *hydrology of the area or just a different plant community, making it more diverse in general, eliminating that fire factor*" (USFWS3). Many respondents concerned with road mortality discussed the usefulness of fencing, but some worried that fencing could impede tortoise movement or that the costs and required extent of coverage limited its feasibility. NPS5 explained, "[*It would be*] *almost 400 miles of fence that we would have to put in … that's … millions of dollars … We'd never get that kind of funding*". Therefore, some managers target tortoise barrier fencing installation where frequent roadkill mortalities have occurred.

Although managers viewed ravens as a top stressor, ravens' protected status creates logistical constraints around raven eradication. One interviewee could not get permission to remove an active raven nest despite finding 20 dead juvenile tortoise hatchlings underneath it. T2 shared their ongoing efforts to get permission to conduct egg oiling: "*Southern California Edison can get it going pretty quickly because they're a large entity. For a smaller tribal entity … it's quite the process*". Instead, raven management often occurred indirectly through outreach and education campaigns, such as advising military personnel or recreationists about the importance of throwing away trash and investing in deterrents like raven-proof trash receptacles.

Education and outreach also targeted other top stressors and was mentioned as an approach by all groups except *multiuse* (*general*). People might worry about touching an endangered species, so outreach by park employees has focused on permissibility and methods to relocate tortoises found on the road. There were also efforts to educate people, such as tribal members or military personnel, on tortoise awareness and the use of proper OHV routes. However, success was variable. T1 explained, "*To tell* [*tribal members*], *'You can go and off-road. It's your land. However, watch out for these little tortoises that look like rocks that are out there when you're zipping by, and go slow' … people think we're taking away their fun*".

Other actions that managers have used as part of tortoise recovery efforts included biological surveys or following broader policy guidelines. Some interviewees spoke generally of surveying tortoise populations, while others shared specific survey types (e.g., presence/absence surveys, telemetry, number of dead juveniles under raven nests). These actions helped determine the effectiveness of management actions or informed decision-making (e.g., where to implement actions). Six people also explained that their management actions were guided by the ESA and/or National Environmental Policy Act (NEPA) compliance and permitting. Three respondents said their site had a formal, county-level or site-specific habitat conservation plan that guided their management decisions.

Finally, several managers mentioned tortoise translocation as a strategy to mitigate the effects of several stressors, such as planned construction, military activities, and renewable energy projects. In contrast to the management actions described above, translocation has not been implemented as a recovery action. In some cases, follow-up monitoring indicated that translocated tortoises are doing well; since 2003, one respondent's program had translocated 577 tortoises, primarily from developed areas. However, other participants worried about the reliance on translocation, especially as it has become commonly proposed to gain approval for solar development projects. For example, BLM6 shared, "they're huge swaths of land that they're taking over and it's just concerning with the connectivity … we don't really have space anymore for translocation … What are we going to do with all these tortoises?"

4 | DISCUSSION

Our results contribute to filling knowledge gaps on the prioritization of stressors on tortoise populations and how perceptions vary across agencies, by region, and over time (e.g., Darst et al., 2013; Tuma et al., 2016; USFWS, 2022). By working with managers from multiple jurisdictions, we co-produced a concise, updated list of what managers believe are priority stressors affecting tortoise populations where they work, identified actions used to address these stressors, and learned about constraints to implementing these approaches. By focusing on only the top priority stressors, our co-produced list provides a tractable set of stressors on which to focus management approaches and support the creation of decision support tools targeting managers' greatest concerns. Given that prioritized stressors can change over time, our results provide a timely re-evaluation of stressors to ensure that current management approaches and recovery actions target the greatest concerns.

4.1 | Manager priority stressors

The co-developed list of priority stressors mirrored many range-wide stressors identified in previous research (Darst et al., 2013; USFWS, 2014a, 2014b, 2014c). Like Darst et al. (2013), we identified urbanization, predation, human visitation and recreation, military activities, and OHVs as the most important stressors. However, some stressors identified in other efforts that have received attention in the past (e.g., disease; Weitzman et al., 2017) were not identified as priority stressors in this study, which may reflect differences in methods and both real and perceived changes in the importance of stressors over time. For example, OHV routes were a greater concern among our respondents than in Darst et al. (2013), potentially due to the continued expansion or increasing knowledge of the extent of legal and illegal OHV trails in the region (Averill-Murray & Allison, 2023).

Examining variation in the importance of stressors over time also allows for understanding where future management efforts should focus. For example, fewer respondents expressed that ravens would be a significant factor driving tortoise populations in the future, which they attributed to the effectiveness of USFWS programs focused on reducing human-subsidized raven populations. In addition, drought, climate change, and wildfire have become increasingly important stressors for tortoises over the last decade and can exacerbate the effects of invasive plant species (St. Clair & Bishop, 2019) on tortoise populations. It is now widely recognized that southwestern North America has been experiencing the worst period of drought since 600 CE (Wahl et al., 2022), contributing to more frequent and severe wildfires (Mueller et al., 2020). Recent fires in the Mojave Desert, such as the 2020 Dome Fire (43,273 acres) (National Park Service 2023) and the Turkey Farm Road Fire (11,699 acres) (Meiners, 2020), can cause direct tortoise mortality and increase prevalence of invasive annual grasses (e.g., cheatgrass [*Bromus tectorum*]) that fuel subsequent wildfires (St. Clair & Bishop, 2019).

4.2 | Stressors across range and missions

Although the range-wide stressors that we identified align with previous studies (e.g., Darst et al., 2013; USFWS, 2014a, 2014b, 2014c), our results provide a more precise and contemporary understanding of geographic variation and jurisdictional site-specific information (e.g., DoD installations). Interviewees suggested that the focus on range-wide stressors has created a mismatch between resulting range-wide management products and local-scale needs. By comparing the responses of those in different recovery units, we saw variation in stressor prioritization across the region. For example, although ravens were most frequently identified as a top stressor across all respondents, respondents in the Upper Virgin River Recovery Unit mentioned urbanization as frequently as ravens, given proximity to the rapid urbanization of St. George, Utah. In addition, renewable energy development was anticipated to be a greater future stressor in the recovery units that include Nevada, whereas new solar development projects are more strictly regulated in recovery units in California (BLM, 2022, 2024). Future studies should address managers' needs for information and scalable, spatial decision support tools that consider variation in local-level stressors.

Overall, those with similar missions but categorized as site-specific or general prioritized the same stressors, although there were some interesting differences among perceived future threats. Most *multiuse (general)* respondents indicated that renewable energy was the greatest future stressor, whereas only one *multiuse (site)* respondent prioritized this as a future stressor. This is possibly because renewable energy installations will not occur at all multiuse sites, but those working at a more general scale see this as a threat across the larger landscape where they work. In contrast, *multiuse* (*site*) respondents prioritized ravens and climate change/drought as more important future stressors than renewable energy. While roads were perceived to be the greatest future stressor among more recreation/wildlife (site) respondents, roads were mentioned by the same number of *wildlife (general)* respondents as were ravens, climate change/drought, and OHVs. Although missions might be similar among individuals, with some even working for the same agencies, these findings illustrate how local observations and experiences may shape managers' views.

Comparing organizational missions also highlighted jurisdictional-specific stressors, such as military activities, which include a wide range of activities whose specific impacts on tortoise populations have not been previously explored. By interviewing those at military installations, we gained greater insight into the impacts of different military actions, including training exercises, construction, and installation-specific foci that result in varying impacts on landscapes and wildlife. Understanding nuances in military operations and subsequent impacts on tortoises may be more important in light of the desert tortoise action plan, which identified the need to develop a methodology to quantify the beneficial effects of recovery actions that would offset negative impacts of military activities (DoD and DOI 2018, 2019; National Fish and Wildlife Foundation, 2022). Concerns exist that tortoise habitat management requirements can present significant regulatory challenges that influence access to military ranges and training areas and can diminish the effectiveness of testing, training, and operational activities (Boice, 2006). However, our findings show that not all military activities are considered to be significant stressors to tortoises, and some installations are already taking actions to avoid tortoise habitat, which can help offset impacts. Some *defense/security* respondents claimed that installations' tight restrictions regarding access and use might provide greater protection for the species, which aligns with Stein et al.'s (2008) findings that TES population densities were much higher on military lands. More research could explore the effects of jurisdiction on tortoise populations, which could inform future tortoise management efforts, including coordinated, cross-jurisdictional management activities.

4.3 | Recovery and mitigation actions

To address stressors, the USFWS (2022) tortoise recovery plan detailed numerous actions to both protect existing populations and habitat (e.g., habitat restoration that addresses invasive weeds, minimize excessive predation on tortoises) and augment depleted populations (e.g., headstarting, translocation). Several participants in this study employed these recovery actions, especially habitat restoration, fencing, environmental education, and decreasing predator access to human subsidies. However, in several situations, managers expressed struggles to take action at the geographic scale necessary to mitigate stressors and increase tortoise population numbers. This challenge was exacerbated by the lack of feasibility to enact several beneficial actions due to funding, regulatory, or scalar constraints. For example, although fencing installation is a potentially effective recovery action (Darst et al., 2013), interviewees expressed that this approach is limited due to cost, extent of fencing required, and user values (e.g., open lands). Similarly, although some studies have posed that short-distance translocation might result in minimal impacts on tortoises (Brand et al., 2016; Dickson et al., 2019), participants were concerned about how often translocation has been used to gain approval for solar installations and worried that tortoises might be moved to sub-optimal habitat. Although translocation can be implemented as a population augmentation strategy (USFWS, 2022), participants discussed translocation primarily in the context of mitigation. Managing for divergent stressors can also lead to conflicting actions that can impact tortoises. Several interviewees highlighted the conundrum when explaining how one of the Biden administration's top proposals for mitigating climate change was to expand renewable energy infrastructure (BLM, 2024; USFWS, 2022), another tortoise stressor.

Knowledge of priority stressors can also help shape accurate topic-specific education and outreach campaigns. For example, whereas tortoise collection was a greater concern in the past, educational campaigns now focus on current issues, such as what to do when finding a tortoise on the road or how to reduce raven presence. Interestingly, Darst et al. (2013) indicated that given the high potential of ineffective environmental education, managers might want to instead invest in other actions. However, environmental education might remain a popular option in addition to these other actions because it can be less cost-prohibitive, tackle several stressors, and be successful (e.g., reduced road mortality or raven presence). For example, visitor behavior educational campaigns can include information on reducing subsidies for predators, tortoise removal from roads, and the importance of responsible OHV use (Ocañas et al., 2022).

4.4 | Value of cross-jurisdictional cooperation and co-production

Addressing important knowledge gaps for TES, such as the tortoise, can enable the development of cohesive, range-wide management strategies aimed toward more effective ecosystem management, priority species recovery initiatives, and partnerships between agencies. The first step is understanding which current stressors impact multiple adjacent jurisdictions, which might be specific to certain jurisdictions (e.g., military activities), and which might impact neighboring lands. Some of these stressors might need to be addressed in partnership, and certain recovery actions might be more feasible if jurisdictions pool resources (e.g., funding, staff; Averill-Murray et al., 2012) to implement actions at scales relevant to recovery.

Our study also illustrates the value of using knowledge co-production approaches to better inform TES species management and support for recovery actions. Through interviews and a workshop, we learned from managers about their on-the-ground experiences and knowledge, which allowed us to identify priority stressors they believed impacted their work. We reaffirmed differences that existed temporally, geographically, and organizationally. Although knowledge co-production approaches have been widely applied to a variety of environmental and conservation issues, such as climate change (Dilling & Lemos, 2011; Meadow et al., 2015), wildfires (Colavito et al., 2019; Grimm et al., 2022), and landscape-scale ecosystem conservation (O'Connor et al., 2021; Páez et al., 2020), fewer studies have focused on situations in which managers from multiple jurisdictions work with each other and scientists to manage and conserve species (Byrd et al., 2023; Kissel et al., 2023). However, examples show the benefits of such collaborations for species conservation, such as understanding manager's needs, validating findings, and co-producing and testing models and tools that can inform where management actions can make a difference (Byrd et al., 2023; Kissel et al., 2023).

Considering these and other outcomes of our research, we believe that knowledge co-production approaches should be employed more often to inform management and conservation of TES species that inhabit areas overlapping multiple jurisdictions. In the United States, agencies working toward recovery of ESA-listed species can have varying impacts due to interagency variation in missions, directives, allowable land uses, management approaches, priorities, and available funding. Our results further demonstrate how knowledge co-production can encourage managers from neighboring jurisdictions to gain an understanding of each other's knowledge and learn from each other's successes and challenges. Such efforts can build capacity for multi-scale application of findings from current projects and set the stage for continued collaborative decision-making (Nel et al., 2016).

AUTHOR CONTRIBUTIONS

Kerry E. Grimm: Methodology; data collection, management, and analysis; workshop facilitation; writing and revising manuscript. Brian Folt: Reviewing and editing manuscript, data visualization, workshop facilitation. Amy Collins: Methodology, workshop facilitation, reviewing & editing manuscript. Madeline Standen: Data visualization, reviewing & editing manuscript. Mark A. Spangler: Methodology, reviewing & editing manuscript. Elissa M. Olimpi: Reviewing & editing manuscript. Brett G. Dickson: Conceptualization, methodology, reviewing & editing manuscript, supervision, funding acquisition.

ACKNOWLEDGMENTS

We thank the managers for participating and sharing their knowledge, C. Darst (USFWS) for interview and workshop preparation insights, and K. Field (USFWS) for manuscript review. L. Allison and R. Averill-Murray (USFWS), K. Nussear (University of Nevada—Reno), and T. Esque (USGS) provided valuable advice on project context, design, and implementation.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

FUNDING INFORMATION

This study was supported through a contract with the US Department of Defense, Strategic Environmental Research and Development Program (project number RC22-3182). Views, opinions, and/or findings contained in this article are those of the authors and should not be construed as an official Department of Defense position or decision unless so designated by other official documentation.

DATA AVAILABILITY STATEMENT

Data from interviews and the workshop supporting findings are shared in the article and supporting information. Raw datasets are not available as they contain identifiable information. Data used to create the jurisdictional map is accessible at https://catalog.data.gov/dataset/blm-natl-sma-surface-management-agency-area-polygons-national-geospatial-data-asset-ngda and https://gbp-blm-egis.hub.arcgis.com/datasets/6bf2e737c59d4111be92420ee5ab0b46/about.

ETHICS STATEMENT

Conservation Science Partners (CSP) does not have an IRB or ethics committee. However, the lead author has completed the Collaborative Institutional Training Initiative (CITI Program) Human Subject Research Training for Social, Behavioral, Education Researchers and is up to date on their certification. We followed CITI 's best practices for ethical human subjects' research in all steps (based on the Belmont Report), including research design, interview guide development, and data collection and storage methods (e.g., informed consent, allowing for participants to skip questions, removing identifiable information). In the email requesting an interview, the lead author provided potential participants with information to help them make their decision (e.g., length, study purpose, confidentiality, how data will be used). Before an interview commenced, the lead author asked if questions remained before deciding to participate, and then confirmed their consent to both participate and be audio-recorded. A similar process was followed with the workshop. Data was secured on the CSP's secure storage drive in a locked folder only accessible to CSP employees involved with the project and had permission. The list of interviewee names and assigned codes was kept separate from the recordings and transcripts that were de-identified and contained on the code. The lead researcher made sure all staff were aware of the ethics protocol.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Grimm, K. E., Folt, B., Collins, A., Standen, M., Spangler, M. A., Olimpi, E. M., & Dickson, B. G. (2025). Applying knowledge co-production to identify Mojave desert tortoise stressors across time, space, and agency missions. *Conservation Science and Practice*, *7*(6), e70073. https://doi.org/10.1111/csp2.70073