

Wicked problems in practice: Responding to ecological transformation in wilderness

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Received: 30 May 2025 / Revised: 13 February 2026 / Accepted: 8 June 2026

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Abstract Congressionally designated wilderness offers the highest level of land protection in the USA, comparable to category 1b wilderness as defined by the International Union for Conservation of Nature, yet wilderness areas face impacts of climate change. Researchers and managers increasingly recognize the immense challenge of stewarding wilderness in a changing climate. Although responding to climate change is considered a wicked problem, this framing has not been applied to wilderness contexts. We move theory into practice by using wicked problem framing and four illustrative cases to explore how the resist–accept–direct (RAD) framework can help untangle the wicked problem of addressing unprecedented ecological transformation in wilderness. The RAD framework clarifies a range of response options including resisting transformation, accepting it, or directing it toward preferred new conditions. As climate change continues to challenge wilderness managers, the RAD framework can help assess trade-offs and preserve wilderness character into the twenty-first century.

Keywords Climate change · Ecological transformation · Wicked problems · Wilderness management

INTRODUCTION

Since the late nineteenth century, global mean temperature has risen $\sim 1.5^\circ\text{C}$, resulting in more extreme weather events, altered disturbance regimes, increased melting of glaciers and ice sheets, rising sea levels, and often amplifying impacts of other more longstanding stressors such as pollution and invasive species (IPCC 2023). Anthropogenic climate change (hereafter climate change) and

climate change-mediated disturbance have widespread cascading consequences for socio-ecological systems (IPCC 2023) and can lead to ecosystems with transformed species composition, structure, and function (Burke et al. 2019; Williams 2022). Climate change can pose additional challenges in parks and other protected areas, particularly those designated to protect certain features or values. For example, Sequoia-Kings Canyon National Park (U.S.)—also designated as a UNESCO Biosphere Reserve and wilderness area—was established to protect over 1/3 of the world’s giant sequoia groves (Shive et al. 2021; National Park Service 2025). Beginning in 2012, a combination of increased temperatures, drought, and bark beetle impacts created the conditions for a series of high-severity fires in the park from 2015 to 2021 (National Park Service 2021). In 2020 and 2021 alone, fires in the park caused a loss of 10–14% of the world’s giant sequoia tree population, and due to the severity of these fires, park staff and scientists are seeing failure to regenerate (Shive et al. 2021; National Park Service 2023). Because giant sequoias are a central management priority, the potentially irreversible loss of the species poses a major threat to the park’s conservation mission.

Preservation-oriented policies that shape global protected area designation, planning, and management have relied on theories of ecological stationarity, where biophysical attributes are assumed to exist within a consistent range of climatic or disturbance-related variability around a measured set of baseline conditions (Jackson and Hobbs 2009; Jackson 2012; Young and Duchicela 2020; Magness et al. 2022; Schuurman et al. 2022). Under a changing climate, however, management approaches that are predicated on the idea of stationarity are fraught with challenges (Milly et al. 2008). Loss of climatic stationarity has been

linked to broadscale ecological transformation or an irreversible change in baseline ecosystem composition, structure, and function (Biggs et al. 2018; Crausbay et al. 2022; Guiterman et al. 2022; Schuurman et al. 2022; Moss et al. 2024). This potential for climate-driven transformation upends conventional management approaches and demands planning strategies that grapple with the uncertainty associated with the rate, magnitude, and direction of future change (Long and Biber 2014; Williams et al. 2021; Clifford et al. 2022; Crausbay et al. 2022; Magness et al. 2022; Cravens et al. 2024).

Congressionally designated wilderness (hereafter wilderness) offers the highest level of land protection in the U.S. and is considered a category 1b wilderness area by the International Union for the Conservation of Nature (IUCN). The IUCN defines wilderness areas as “usually large unmodified or slightly modified areas, retaining their natural character and influence, without permanent or significant human habitation, protected and managed to preserve their natural condition” (Dudley 2008, 14). In the US, wilderness is a legally defined protected area codified into law with the passage of the Wilderness Act of 1964 (hereafter the Wilderness Act), which provides the legal definition of wilderness and establishes the National Wilderness Preservation System. The National Wilderness Preservation System currently encompasses 111 million acres of land managed by four federal land management bureaus: the U.S. Forest Service, Bureau of Land Management, Fish and Wildlife Service, and National Park Service. These federal bureaus have, in turn, developed guidance for managing wilderness (e.g., National Park Service 2022); although such stepped-down management guidance may challenge or enable exploration of all climate adaptation options, full exploration here is beyond the scope of this paper. The primary mandate of the Wilderness Act is to preserve “wilderness character” (Fig. 1; The Wilderness Act 1964). Although undefined in the Wilderness Act, an interagency team operationalized wilderness character as “a holistic concept” encompassing the relationship among biophysical, experiential, and symbolic ideals (Landres et al. 2015, 7). To implement a national strategy to monitor wilderness character, the agencies interpreted it to include five distinct qualities derived from the definition of wilderness within the Act: (1) untrammeled, (2) natural, (3) undeveloped, (4) opportunities for solitude or primitive and unconfined recreation, and (5) other features of value (Landres et al. 2015; see Fig. 1 for definitions). Although wilderness is ideally stewarded to optimize all of these qualities, some situations put these qualities into competition. For example, to preserve a riparian area (i.e., naturalness), managers may need to construct a bridge across the stream. Building this bridge would help protect the natural quality; however, it would

harm the undeveloped quality of wilderness character (Landres et al. 2015). Central to this paper are the ways in which maintaining natural and untrammeled qualities come into conflict in the context of climate-driven ecological transformation.

Although wilderness areas are afforded the highest level of protection, they are still susceptible to direct and indirect impacts of climate change (Holsinger et al. 2019; Aycrigg et al. 2022). Wilderness managers must, therefore, weigh difficult choices regarding if and how to respond to observed or anticipated ecological changes (Stephenson and Millar 2012; Higgs and Hobbs 2010; Aycrigg et al. 2022; Kelly and Landres 2023). Active management of wilderness to address ecological change is considered trammeling, even if the goal of intervention is to maintain or enhance the natural quality of wilderness character (Landres et al. 2015). Therefore, decisions to intervene are often highly scrutinized and require thoughtful design and detailed justification to withstand legal and ethical scrutiny (Landres 2004; Higgs and Hobbs 2010). Whether or not and how to undertake climate-adaptive actions in wilderness poses a “wicked problem” for wilderness managers—one that has no right or wrong answers, but many potential ecological, social, and legal consequences (Rittel and Webber 1973; Balint et al. 2011).

As climate-driven transformation continues to occur in wilderness, scholars and agencies have identified the need for decision support tools to help managers navigate this wicked problem, and have introduced several frameworks (e.g., Higgs and Hobbs 2010; Stephenson and Millar 2012; Stein et al. 2014; Swanston et al. 2016). Despite the proliferation of management frameworks, few help managers recognize and work with a broad range of response options that may be appropriate in wilderness contexts. The RAD framework is a relatively new tool that does so and is designed to fit within multiple existing climate adaptation processes (Miller et al. 2025; Schuurman et al. 2025; Sesser et al. 2025). In particular, the RAD framework helps managers identify the range of potential management strategies as they review and reconsider their management goals and approaches given current and future climatic and ecological trajectories (Miller et al. 2025; Schuurman et al. 2025). RAD may be especially well-positioned to assist wilderness managers in navigating the wicked wilderness problem because it (1) is specifically designed to support a manager’s response to ecological transformation, (2) encourages managers to consider the option of not actively intervening in the transformation, (3) can be used at a landscape scale across jurisdictions and land designations, and (4) fosters intentional choice among a suite of options that range from managing for persistence to managing for change.

Wilderness Character
Untrammeled Wilderness is essentially unhindered and free from intentional actions of modern human control or manipulation.
Natural Wilderness ecological systems are substantially free from the effects of modern civilization; wilderness contains native species compositions and their ecological functions.
Undeveloped Wilderness does not contain permanent improvements or the sights and sounds of modern human occupation.
Provides solitude or primitive and unconfined recreation Wilderness offers outstanding opportunities to experience a sense of privacy, inspiration, connection to the past, and being untethered from civilization. Additionally, wilderness offers outstanding opportunities to freely travel by non-motorized or non-mechanized means, rely on personal skills, and experience challenge and personal growth.
Other features of value Wilderness may contain unique ecological, geological, or other features of scientific, educational, scenic, or historical value.

Source: Landres, P.; Barns, C.; Boutcher, S.; Devine, T.; Dratch, P.; Lindholm, A.; Merigiano, L.; Roeper, N.; Simpson, E. (2015). Keeping it wild 2: an updated interagency strategy to monitor trends in wilderness character across the National Wilderness Preservation System. Gen. Tech. Rep. RMRS-GTR-340. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 114 p.

Fig. 1 Definitions of wilderness character qualities from Landres et al.'s (2015) Keeping it wild 2: An updated interagency strategy to monitor wilderness character across the National Wilderness Preservation System

Climate change and managing for its impacts are well-documented wicked problems (Chapin et al. 2008; Lazarus 2009; Levin et al. 2009; Levin et al. 2012; Conradie 2020; Gilligan and Vandenberg 2020). Wicked problems have been explored in numerous planning contexts including urban planning (e.g., Adams 2011; Asadi and Arbab 2024), national forest planning (e.g., Balint et al. 2011), and health and social care (e.g., Thomas et al. 2018), as well as for responding to and preparing for climate change-related impacts (Chapin et al. 2008; Lazarus 2009; Levin et al. 2009, 2012). Although research about the wicked problem of climate change is abundant, this framing has not yet been brought to the wilderness context. This lack of application is surprising given that, as with other types of protected areas, upstream causes of climate change are beyond local wilderness managers' control, yet managers are tasked with addressing the impacts. Managing the effects of climate change in wilderness is further

complicated by layers of legal requirements established to preserve competing qualities of wilderness character. Thus, wilderness management decisions are often highly scrutinized because management actions to support one quality of wilderness character (e.g., naturalness) increasingly come at the expense of other qualities (e.g. untrammeled) or vice versa. This paper moves theory into practice by understanding this problem through wicked problem framing and exploring how the RAD framework can help make the problem more approachable.

GRAPPLING WITH WICKED PROBLEMS

Wicked problems are deep-rooted societal and ecological problems that are so complex, uncertain, and value-based that people disagree about how to define and thus how to address them (Rittel and Webber 1973; Chapin et al. 2008).

In their 1973 article, Rittel and Webber introduced the term “wicked problem” and identified ten interrelated properties that set these problems apart from “tame problems,” which are more well-understood and have correct or incorrect solutions (Fig. 2; Rittel and Webber 1973; Balint et al. 2011). Across planning contexts, wickedness stems from high degrees of complexity and scientific uncertainty along with ambiguous and value-based definitions of the problem and solutions (Rittel and Webber 1973; Balint et al. 2011; Gilligan and Vandenberg 2020; Asadi and Arbab 2024). As a result, there are no wholly correct or incorrect answers to wicked problems (i.e., in mathematical decision analysis

terms, there is no one optimal solution). Because they are defined by the values of each beholder, answers may only be evaluated as better/worse or good enough (Rittel and Webber 1973; Balint et al. 2011; Gilligan and Vandenberg 2020). Additionally, because wicked problems can be formulated or defined in innumerable ways, they have many possible solutions, and thus, no clear criteria exist to determine when a solution has been reached (Rittel and Webber 1973).

Research across planning contexts has provided approaches to help navigate wicked problems. For example, Balint et al. (2011) suggest following a participatory

The Wicked Problem of Managing for Climate Change in Wilderness	
Every wicked problem is the symptom of another problem. Rittel and Webber (1973) • Problem so widespread there is no logical end to problem • Every wicked problem can be considered a symptom of another problem Balint et al. (2011) • Uncertain or incomplete knowledge creates an inadequate basis for informing decisions • Ambiguity about budgets and lack of procedural continuity results in inadequate implementation	Solutions are highly contested. Rittel and Webber (1973) • No opportunity to learn by trial and error. Every attempt counts significantly. • The planner has no right to be wrong Balint et al. (2011) • Ambiguity about political coalitions and power results in lack of clarity about which values should dominate and prevail • Multiple stakeholders with multiple value sets and power structures lead to conflicting definitions of success
There are many ways to frame and approach the problem. Rittel and Webber (1973) • Problem formulation impossible because no consensus definition of problem or solutions • People's worldviews differentiate discrepancies in problem definitions and solution Balint et al. (2011) • Multiple perspectives on the problem create ambiguity about the nature of the problem • Because success is often determined by objectives, ambiguity in the problem begets lack of clarity about successful outcomes • Values determine the criteria by which success is judged, so ambiguity in these criteria creates lack of clarity about successful outcomes	Every solution has consequences; solutions are not right or wrong, only better or worse. Rittel and Webber (1973) • Wicked problems do not have true/false answers because they are not definable, only better/worse or good enough. • Any solution will have repercussions affecting innumerable communities over an unbounded amount of time, thus difficult to test effectiveness • No way to know that all potential solutions have been identified • Every wicked problem is unique, making transferability of knowledge difficult Balint et al. (2011) • Static solutions do not work in dynamic contexts where problems are changing and evolving • Lack of clarity about objectives and criteria for judging success result in lack of clarity about how best to proceed

Fig. 2 Distilled properties of a wicked problem derived from Rittel and Webber (1973) and Balint et al. (2011) as relevant to managing for climate change-driven ecological transformation in wilderness

planning process that creates a learning network among stakeholders. Further, Balint et al. (2011) urge land managers not to seek a perfect solution; instead, they should seek a “satisficing” solution, or one that is acceptable and implementable without an expectation that it is the optimal or the best solution (Simon 1957). In contrast with a single satisficing solution, Lindblom’s (1959, 1979), “science of muddling through,” focuses on small steps to address pieces of the larger problem (e.g., Chapin et al. 2008). Some use the metaphor of applying bet hedging or “silver buckshot” to accommodate several different but complementary approaches, each addressing a subset of challenges, rather than seeking a “silver bullet” (Weber 2015; Brook et al. 2018; Boykoff 2019). Thus, no single action will solve the problem, but complementary actions maximize chances of ameliorating the problem. Further, Levin et al. (2012) urge planners to use “applied forward reasoning” in their planning because decisions related to climate change must look into the future and account for upcoming challenges in addition to current ones.

To describe the wickedness of managing climate change in wilderness, we adapted prior wicked problem frameworks (i.e., Rittel and Webber 1973; Balint et al. 2011) by distilling their properties or conditions into four critical elements (Fig. 2): Element 1: *Every wicked problem is the symptom of another problem*; Element 2: *There are many ways to frame and approach the problem*; Element 3: *Every solution has consequences; solutions are not right or wrong, only better or worse*; and Element 4: *Solutions are highly contested*.

MANAGING FOR CLIMATE CHANGE IN WILDERNESS: A WICKED PROBLEM WITH RAD SOLUTIONS

The RAD framework is a relatively new tool for climate adaptation planning that could help managers untangle the wicked problem of addressing climate change impacts in wilderness. RAD presents three avenues for addressing anticipated ecological transformation: (1) resist the transformation by maintaining historical or current conditions through restoration and other interventions such as mitigation, (2) accept the transformation by intentionally allowing ecological composition, structure, and function to change autonomously—without human intervention, or (3) direct the transformation by actively shaping ecological changes toward a preferred new condition (Schuurman et al. 2020, 2022; Lynch et al. 2021; Thompson et al. 2021). Designed by and for natural resource managers, the RAD framework is action-oriented, meaning that it focuses on how managers can respond to transformation, and includes the choice not to intervene in the ecological

trajectory. The RAD framework encourages managers to think across the whole decision space of potential responses to transformation (Schuurman et al. 2022). RAD may be a particularly appropriate framework for wilderness managers because it offers the option to accept ecological change, which is a common strategy to promote the untrammelled quality of wilderness character (USDA Forest Service 2024).

The RAD framework was designed for application in existing processes that promote climate-adaptive decision-making (Schuurman et al. 2025) like the interagency Climate-Smart Conservation Cycle (Stein et al. 2014) and the Adaptation Workbook process (Swanston et al. 2016). By providing a suite of possible management actions to choose from, including a deliberate choice for “no action” (e.g., “accept”), the RAD framework also aligns with federal decision-making processes on public lands such as Minimum Requirements Analysis Framework required for wilderness (Arthur Carhart National Wilderness Training Center 2024), and those required under the National Environmental Policy Act (National Environmental Policy Act of 1969). As a result, the RAD framework is currently being incorporated into existing climate adaptation policy (*National Wildlife Refuge System Planning Policies 602 FW 1* 2024; National Park Service *Policy Memorandum 24–03 Managing National Parks in an Era of Climate Change* 2024) and guidance (e.g., the U.S. Department of the Interior 2021; the USDA Forest Service 2024) for wilderness-administering agencies. The integration of the RAD framework across agencies’ policies and guidance and adaptation planning guides and its alignment with other decision-making requirements may facilitate its use in collaborations across agency jurisdictions and land designations (Miller et al. 2025).

The following sections describe how each element of the wicked problem manifests within the wilderness context, using real-world case studies. We then apply the RAD framework to each element and case to demonstrate how RAD can help untangle each critical element and the greater wicked problem of managing for climate change impacts in wilderness.

Critical element 1: Every wicked problem is the symptom of another problem

Rittel and Webber (1973) assert that every wicked problem can be considered the symptom of another problem. Managing for climate change in wilderness is a symptom at the confluence of several other problems including all the anthropogenic causes of climate change, the need to preserve wilderness character qualities with conflicting goals, and other compounding issues that have transformed wilderness landscapes such as histories of human use and

previous land management decisions (Jones et al. 2022; Kreider et al. 2024). Rittel and Webber (1973) recommend resolving root causes of wicked problems at the highest level possible; however, wilderness managers cannot solve the root causes of climate change, nor can they clarify the vague language of the Wilderness Act. As such, there is no clear way to address the root causes of climate change impacts within wilderness.

As mentioned, the Wilderness Act has several goals, including maintaining the natural qualities of wilderness while also leaving wilderness areas as untrammeled (i.e., without modern human intervention). However, the question about what constitutes “natural” is a longstanding and unresolved issue, particularly as it relates to the relationship between humans and non-human nature (Aplet and Cole 2010; Yung et al. 2010; Boerigter et al. 2024). Wilderness stewards and scientists are increasingly working to understand people’s role in wilderness ecosystems and pursue appropriate human–wilderness relationships. The Wilderness Act defines wilderness as “retaining primeval character and influence” (The Wilderness Act 1964, Sect. 2c), which scholars now recognize was in many cases shaped by Indigenous land stewardship from time immemorial until widespread forced assimilation, removal, and/or relocation of Indigenous populations in the U.S. (Kimmerer and Lake 2001; Klimaszewski-Patterson and Mensing 2020; Lake and Christianson 2020; Hessburg et al. 2021). For example, the removal of Indigenous land stewardship practices, such as cultural burning, coupled with the onset of aggressive large-scale fire suppression since the early twentieth century, has pushed many fire-adapted wilderness ecosystems away from historical fuel loads and has increased the likelihood of high-severity fire—further risking wholesale ecological transformation (Fig. 3; Calkin et al. 2015; Boerigter et al. 2024).

Applying the RAD framework to address critical element 1

The RAD framework inherently encourages land stewards to consider future ecological trajectories because it centers all resist, accept, and direct response options on ecological transformation (Schuurman et al. 2020, 2022; Magness et al. 2022). For example, in the Boundary Waters Canoe Area Wilderness (Fig. 3), loss of open red pine forest (i.e., the ecological transformation) is a symptom of other problems such as loss of human-ignited surface fire (Larson et al. 2021). Fire exclusion in the Boundary Waters has made the forest more dense and homogenous, rendering it more susceptible to high-intensity fire and influences of climate change such as drought—both of which are predicted to increase in frequency and severity in future (Larson et al. 2021). Once the cause and the transformation are identified through a vulnerability assessment, managers

could use the RAD framework to identify decision alternatives that specifically respond to the identified cause. Hypothetical examples in this case could include: resisting the loss of red pine forests by restoring human-ignited surface fire, accepting the loss of red pine forests by choosing to not intervene, or directing the transformation by actively facilitating the regeneration of near-boreal forest species or other forest species that may be better adapted to (future) climate (Schuurman et al. 2022).

Critical element 2: There are many ways to frame and approach the problem

A key characteristic of wicked problems is that problem definitions are contested and intimately tied to central value debates among those trying to ameliorate the problem. As a result, solutions become almost impossible to agree upon (Rittel and Webber 1973; Balint et al. 2011). Law, policies, interagency guidance, worldviews, and values all shape how managers and the public perceive the problem and, subsequently, conceive solutions for it (Clifford et al. 2022). The regulatory environment for managing climate change impacts in wilderness is complex because the Wilderness Act does not provide a clear definition of wilderness character, and interpretations of the law in interagency guidance and management policy can provide conflicting directions. In addition to regulatory complexity, this problem is socially complex because managers and the public may have varying worldviews and values that influence their interpretation of the Wilderness Act, perception of the problem, as well as the appropriateness of any given solution.

Wilderness character is not defined in the Act, nor does the Act indicate that any one quality of wilderness character is more or less important than another (The Wilderness Act 1964; Landres et al. 2015). Other intersecting legislation (e.g., Endangered Species Act 1973 and National Park Service Organic Act 1916) prioritizes conserving natural conditions, and there is little federal guidance or research on how adjacent laws intersect with the Wilderness Act. Furthermore, the different bureaus charged with managing wilderness, and other natural resources, were created from various legislation that have likely influenced organizational culture around priorities for and values of natural resources and wilderness (Ginger 1998; Swing 2011).

In addition to law and policy, worldviews, or the ways that people see themselves in relation to the world, are important factors that affect how managers interpret the Wilderness Act and understand the wicked problem and potential solutions, if they perceive a problem at all (Rittel and Webber 1973; Koltko-Rivera 2004; Clifford et al. 2022; Howe et al. 2024). Worldviews can shape meanings

Problem Element: Every wicked problem is the symptom of another problem.

RAD Application:

The RAD framework helps broaden perspectives and reveal the ultimate problem. The framework encourages a strong and clear focus on the upstream causes of local impacts, which may be difficult or impossible to resist. The framework therefore requires consideration of alternative response strategies.

Illustrative Case: Anishinaabe people traditionally used cultural burning in today's Boundary Waters Canoe Area Wilderness, which could be considered the area's "primeval...influence". With the removal of the Anishinaabe, cultural fire was likewise removed from the ecosystem—threatening fire-adapted systems. Assessment of climate-change implications clarifies that RAD-based responses must address loss of fire from the system.



Fig. 3 Fire exclusion in the Boundary Waters Canoe Area Wilderness is an example of the first critical element of the wicked problem: Every wicked problem is the symptom of another problem. Photo credits from left to right: USDA Forest Service; USDA Forest Service; Kal Jordan-DeBruin, USDA Forest Service; Josh O'Connor, US Fish and Wildlife Service

of concepts such as naturalness or untrammelled land. For instance, meanings of untrammelled have largely focused on *how land is managed*. In the case of wilderness, untrammelled has been interpreted as allowing the land and its inhabitant species to change autonomously, or managed with little to no human intervention, and has been valued as a place where humans exercise humility and restraint (Cronon 1996; Landres et al. 2015). Cultural meanings of naturalness are more diverse (Cole and Yung 2010). Historically, Western worldviews and meanings of naturalness have focused on the *condition of the land* lacking human impact and maintaining fidelity to current (or past) ecosystem composition, structure, and function (National Park Service 2006; Aplet and Cole 2010; Stephenson and Millar 2012). By contrast, many North American Indigenous worldviews see humans as part of nature, and that people are responsible for taking care of their non-human

kin across the natural world (Deloria 2003; Tinker 2010). From this perspective, actively tending current and ancestral homelands is perfectly natural and demonstrates foresight, care, and reciprocity. These differences in worldviews and values for varying wilderness character qualities can shape how individuals perceive the problem and what they identify as appropriate responses.

Applying the RAD framework to address critical element 2

The RAD framework can help untangle the wickedness of critical element two (i.e., there are many ways to frame and solve the problem) because it can challenge assumptions about what the future will be like, including those related to causes of transformation, sources of uncertainty, and the scale of the issue. The RAD framework also encourages managers to consider a suite of strategies and associated

actions to intervene, or not, in the ecological transformation. This suite of actions may represent a variety of ways to approach the problem and a continuum of intervention from passive (less intrusive to the untrammeled quality) to active (more intrusive) (Chazdon et al. 2024), which could reflect a continuum of worldviews and values regarding wilderness and its management.

Managing climate change impacts within wilderness is particularly complex in Alaska because the Alaska National Interest Lands Conservation Act (ANILCA) mandates balancing multiple, and sometimes conflicting, interests, values, and worldviews in Alaska wilderness management (Fig. 4). For example, increasing winter temperatures in interior Alaska are resulting in unpredictable and unstable inland ice—making traditional travel mechanisms unsafe (Wendler and Shulski 2009; Schneider et al. 2013; Cold et al. 2020). Hypothetically, someone who primarily values wilderness for subsistence may see this as a major threat for their hunting access and advocate for resisting or directing the change for continued access for subsistence hunting. Alternatively, someone who primarily values wilderness for solitude and primitive recreation may be happy to see reduced motorized use (which is allowed in ANILCA wilderness; Fig. 4) and advocate for accepting the transformation. Both perspectives are valid ways of framing the problem, and both solutions would uphold the goals of ANILCA and the Wilderness Act. Therefore, considering diverse interests could support both local communities and the intentions of the Wilderness Act. To accommodate diverse interests, managers, stakeholders, and rightsholders can come together through pre-existing mechanisms such as the Alaska National Interest Lands' Federal Subsistence Board and Regional Advisory Councils to identify and weigh RAD responses to climate change impacts to access, subsistence, and lifeways.

Critical element 3: Every solution has consequences; solutions are not right or wrong, only better or worse

There are no technically correct or optimal solutions to wicked problems (Rittel and Webber 1973; Balint et al. 2011), and this is particularly true for managing climate change within wilderness because the Wilderness Act does not prioritize any one quality of wilderness character, and different qualities can have conflicting goals in the context of responding to climate change impacts. Stephenson and Millar (2012) asserted that climate change is wilderness' greatest challenge because managers would increasingly have to make trade-offs between untrammeled and natural, primeval qualities of wilderness. Optimal solutions to climate change elude wilderness managers because of the complex implications for natural and untrammeled

wilderness character, diverse values, and implications for the broader community of life. A survey across the National Wilderness Preservation System found that 37% of wilderness areas engaged in active management between 2011 and 2015, and that many of these actions were considered restoration efforts for vegetation, wildlife, and aquatic systems (Lieberman et al. 2018). These activities supported the natural quality of wilderness but came at the expense of trammeling. Both decisions to restore or to not restore could be considered acceptable options with trade-offs. To provide another example, piñon-juniper woodland management in wilderness has been an increasingly challenging issue because all management options have numerous consequences (Fig. 5). The consequences associated with each option are perceived as more or less tolerable according to each concerned party and depending on geographical context, values, and priorities (Fig. 5).

Applying the RAD framework to address critical element 3

The RAD framework helps illuminate a decision space, thereby fostering productive conversation of the multifaceted implications of alternative strategies (Runge et al. 2020; Lynch et al. 2022; Miller et al. 2025; Schuurman et al. 2025). Documenting managers' considerations of potential impacts to wilderness character alongside other implications is imperative to support robust and defensible decision-making in wilderness. Furthermore, in an era of unprecedented ecological change, identifying all potential implications is key to acknowledging uncertainties and selecting an alternative(s) that may minimize risk and meet desired conditions.

In the western U.S., semi-arid woodlands composed of piñon (e.g., *Pinus edulis* and *P. monophylla*) and juniper (e.g., *Juniperus monosperma* and *J. osteosperma*) are at the nexus of several often-competing issues and priorities for land managers. Specific implications of resist, accept, or direct alternatives for addressing woodland transformation are inherently dependent on geographic location, scale, and the unique cultural and social values of affected persons and communities. In Bandelier National Monument, resisting the increase of woodland density through actions such as thinning and prescribed fire may be vital to protect unique archeological sites and native understory vegetation threatened by changes in wildfire frequency and intensity (Sydoriak et al. 2000). Because archeological sites are considered important features of value (Fig. 1) and hold cultural significance, these actions would be consistent with the intent of the Wilderness Act. However, preserving these features comes at the cost of trammeling the wilderness. On a landscape-level, semi-arid woodlands are generally losing ground where climate change-driven drought, high intensity wild fire, and bark beetle

Problem Element: There are many ways to frame and approach the problem.

RAD Application: The RAD framework is inherently amenable to a diversity of problem framings and approaches because it is designed to encourage broad, clear consideration of a suite of potential responses. The suite of response options can reflect the varied values and interests of managers, rightsholders, and stakeholders.

Illustrative Case: The passage of the 1980 Alaska National Interest Lands Conservation Act (ANILCA) established federal lands (including wilderness) and incorporated diverse interests in their management (e.g., allowing for motorized access for subsistence users and inhabited wilderness). Often, issues of access and subsistence are fraught with conflict originating from divergent worldviews and values. By focusing on developing a diverse set of potential responses to address the problem, RAD application provides opportunities to share and work with diverse perspectives regarding not only how to address the problem but also about the nature of the problem.

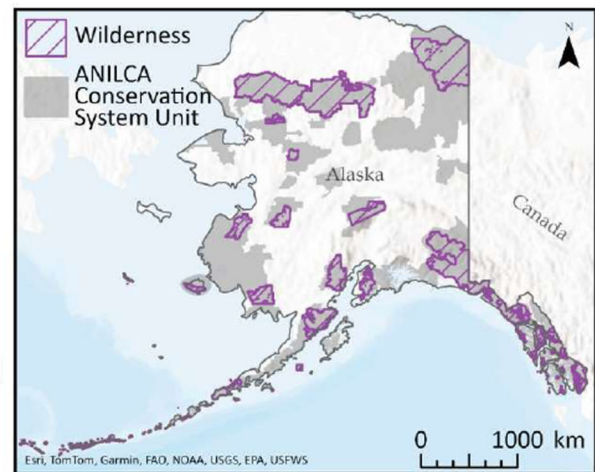


Fig. 4 Managing wilderness areas established by the Alaska National Interest Lands Conservation Act is an example of the second critical element of the wicked problem: There are many ways to frame and approach the problem. Photo credits from left to right: Teresa Hollingsworth, USDA Forest Service; Teresa Hollingsworth, USDA Forest Service; Hillebrand, Bureau of Global Public Affairs; T. Vaugh, US National Park Service

infestations are leading to unprecedented rates of mortality (Breshears et al. 2005). Choosing to continue stand removal and thinning treatments across large geographic regions may exacerbate ongoing impacts of climate change, further threatening the persistence of woodland-dependent species, old-growth forests, and cultural resources (Redmond et al. 2023). At this scale, managers may consider a portfolio approach of RAD alternatives across both space and time to reduce impacts on the untrammelled quality of wilderness while also promoting the historical and natural qualities of these important woodlands (Thompson et al. 2021; Ward et al. 2023).

Critical element 4: Solutions are highly contested

Management decisions are often highly contested because of disputed ways of framing the problem, competing values, and the relative importance of wilderness character qualities (e.g., Cole et al. 2016; Landres et al. 2000). Although trammeling is meant to be avoided, the Wilderness Act allows intervention in wilderness if it is well-justified (Landres 2004; Long and Biber 2014). This ambiguity creates substantial discretion for individual managers to make decisions based on their expertise and best available science, but it puts management agencies at risk of litigation because these decisions are so contentious.

Problem Element: Every solution has consequences; thus, solutions are not right or wrong but better or worse.

RAD application: The RAD framework is designed to help users produce a set of divergent potential responses from which choices will be made and therefore supports careful deliberation among a set of solutions in which responses are not inherently right or wrong but some may be considered better or worse for local contexts.

Illustrative case: In the Intermountain West, piñon-juniper woodlands are important biocultural ecosystems, yet land management practices such as fire exclusion have contributed to their encroachment on sagebrush steppe habitat and increased risk for high severity fire. Despite their expansion, piñon-juniper woodlands are increasingly threatened by climate-change induced drought, high intensity wildfire, and bark beetle infestation. Choosing to actively manage encroachment and infill may exacerbate on-going impacts of climate change, further threatening these ecosystems, yet ceasing treatments may threaten sagebrush-obligate species. The alternatives that result from RAD application clarifies and distinguishes these options, allowing decision makers to choose what they consider the best option.

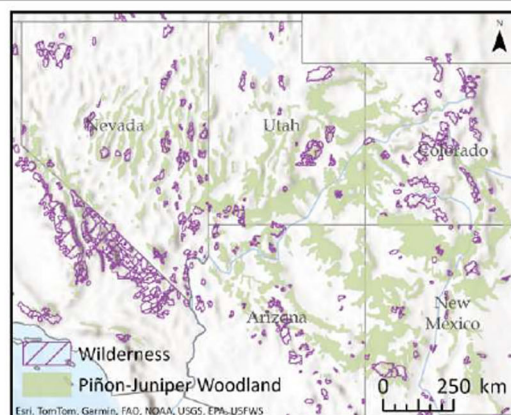


Fig. 5 Decisions about piñon-juniper management are an example of the third critical element of the wicked problem: Every solution has consequences; solutions are not right or wrong, only better, or worse. Photo credit for both images: Sam Flake

There is a considerable history of litigating active management intervention in wilderness (Appel 2011; Kammer 2013; Long and Biber 2014), and the U.S. courts have been more likely to scrutinize agency decisions in wilderness as compared to other publicly managed lands (Appel 2011). Additionally, because the Act is ambiguous in its definition of wilderness character, court decisions “ultimately depend upon the court’s interpretation of Wilderness Act provisions, including the Act’s purpose [and] its definition of ‘wilderness character’” (Kammer 2013, 91).

Litigation can be an important opportunity to examine agency action and instill more thoughtfulness in decision-making, such as in Kofa National Wildlife Refuge (Fig. 6). However, land managers can perceive litigation as constraining professional expertise and hampering effective management because litigation typically requires large amounts of funding and staff capacity and requires agencies to halt all action until a judicial decision has been reached (USDA Forest Service 2002; Keele et al. 2006;

Kemp et al. 2015). When agency decisions are contested in court, there are profound repercussions for the wilderness in question and, when a legal precedent is set, for the future of wilderness decision-making across the National Wilderness Preservation System.

Applying the RAD framework to address critical element 4

Like other climate adaptation frameworks, the RAD framework was designed to help managers identify a range of strategies for responding to ecological transformation (Schuurman et al. 2020, 2022). Importantly, the RAD framework is a tool for generating options and is not a decision-making process. It does not prescribe evaluation of the response alternatives it helps to identify. However, when used in a decision-making process that evaluates the response alternatives, the RAD framework can help ensure that wilderness managers are prepared for a high level of scrutiny. Having a record of the rationale behind

Solutions are highly contested.

RAD Application: Because RAD fosters a diverse and divergent set of options organized among three broad categories, it provides structure that helps a decision maker document consideration of these options and justify and defend the ultimate decision.

Illustrative Case: Kofa National Wildlife Refuge installed artificial water sources, or guzzlers, to provide water for desert big horn sheep due to drought, habitat fragmentation, and the diversion of water for use in adjacent communities. This decision was highly contentious due to impacts to wilderness character and resulted in litigation. The courts ruled that the Fish and Wildlife Service needed to better justify that the installation was the minimum action necessary for maintaining desert big horn sheep in the wilderness.

Using the RAD framework could help managers justify their climate adaptive decisions by showing (1) that diverse options—including non-intervention or acceptance of change—were developed in a structured way, and (2) that this structure encouraged transparent and strategic deliberation.

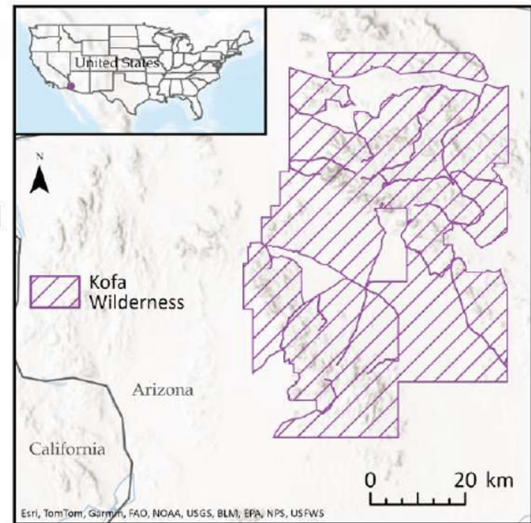


Fig. 6 The litigation of installing artificial water sources for desert big horn sheep in Kofa exemplifies the fourth critical element of the wicked problem: Solutions are highly contested. Photo credits from left to right: Beau Rogers; Johnida Dockens; Gene Spedsard

wilderness management decisions demonstrates intentionality (i.e., decisions are not arbitrary and capricious).

Documented consideration of multiple resist–accept–direct alternatives could help justify management decisions in the face of litigation. For example, although appeals court judges found that the conservation of desert bighorn sheep in Kofa was consistent with the intent of the Wilderness Act, they felt that the U.S. Fish and Wildlife Service did not sufficiently explore alternative management approaches to installing water tanks. Therefore, the court felt that the agency could not defend water tank installations as the minimum action necessary to conserve desert bighorn sheep (“Wilderness Watch, Inc. v. U.S. Fish and Wildlife Service” 2010). Thus, documenting a range of actions to resist, accept, or direct the loss of surface water and the implications of each strategy for species conservation and wilderness character may have been useful in the agency’s defense.

Although this case is now closed, surface water availability for wildlife is an ongoing issue in the U.S. Desert Southwest, especially in the context of climate change. Thus, the lessons learned in this case can inform future actions to store and/or supplement water for wildlife in wilderness. In a space where optimal solutions do not exist and perceptions of the problem and its solutions are value-based and highly contested, documenting the development and evaluation of RAD alternatives can help justify manager decisions.

DISCUSSION

Climate change and related compounding disturbances such as altered fire regimes, native and invasive insect and pathogen outbreaks, and reduced water flows are threatening to transform wilderness ecosystems and will continue

to do so (Davis et al. 2019; Aycrigg et al. 2022; Guiterman et al. 2022). RAD may be a particularly appropriate framework for wilderness managers because it centers on managing for ecological transformation and offers the option to intentionally accept change, which may promote the untrammelled quality of wilderness character (USDA Forest Service 2024; Schuurman et al. 2025). The RAD framework can help address each critical element of the wicked problem (Fig. 7). Further, several resist, accept, and direct strategies can be implemented across space and time as part of a complementary, portfolio approach that maximizes positive outcomes while minimizing negative ones or that may help manage risks to ecological communities by diversifying strategies across space (Aplet and McKinley 2011; Thompson et al. 2021; Magness et al. 2022; Noel et al. 2023). Additionally, because the RAD framework is already being used by the four U.S. wilderness-administering bureaus (e.g., the U.S. Fish and Wildlife Service 2024; National Park Service 2024; and USDA Forest Service 2024), it has potential to support both local and landscape-level planning—across jurisdictions and land designations. All these attributes allow managers to use one framework, which streamlines and facilitates integration of wilderness into transboundary climate-adaptive management. Future research could explore the application of the RAD framework across U.S. wilderness lands and could advance understanding of its effectiveness as an interagency framework to help untangle the wicked problem of managing for climate change in wilderness.

Considerations for applying the RAD framework

Despite the manifold strengths of the RAD framework, there are important considerations when applying RAD to the wicked problem of responding to climate change in wilderness. First, as stated above, the RAD framework is not a complete, standalone planning and decision-making process; instead, RAD is intended to be used within processes that include other steps, such as steps where decision makers use other tools and approaches to choose an option from a range of divergent alternatives, implement it, and track its effectiveness (Miller et al. 2025; Schuurman et al. 2025; Sesser et al. 2025).

Second, resisting, accepting, or directing transformation may be interpreted differently and found more or less acceptable across organizational and cultural boundaries. Conservation agencies that focus strongly on preserving ecological integrity, for example, may view options to accept or direct changes in ecosystem composition, structure, and function very differently from partners who see working with climate change-driven biodiversity redistribution as a key strategy for landscape-level conservation.

In addition, resource managers, local communities (stakeholders), and Indigenous partners (rightsholders) may—because of differences in culture or historical experiences—view resist, accept, or direct options and explanatory language (e.g., regarding relocation of species) very differently. Thus, early and frequent engagement with rightsholders and stakeholders is critical for recognizing and working with key differences in perspectives and developing a shared lexicon and understanding regarding divergent potential responses to climate change-driven ecological transformation. Future research could explore how different communities and cultures perceive ecological transformation and the categories of response under the RAD framework, and how best to engage different ways of knowing and stewarding natural systems effectively and ethically.

Third, given the emphasis on managing wilderness as untrammelled, some managers may be more reluctant to adopt strategies that intervene in the ecological trajectory by resisting or directing transformation than they are to choose acceptance strategies within wilderness, despite all three options generally being considered equally valid. Deciding whether or not to intervene in ecological trajectories is value-laden, and the ambiguity of the Wilderness Act allows for significant manager discretion in this regard (Katz 1992; Landres 2010). Future research could explore how wilderness managers' values relate to their normative beliefs about wilderness stewardship given climate-driven ecological transformation.

International implications

Although this paper focuses on the U.S. wilderness, the perspectives shared here have global relevance. U.S. ideas about national parks, wilderness, and other protected areas have influenced other nations' conceptual and legal approaches to conservation from the late nineteenth century on, such as New Zealand (Cravens 2008; Carver et al. 2014). The addition of category 1b wilderness areas to the IUCN's Protected Areas Management Guidelines was recommended in 1984 and then formally adopted in 1992 (Martin et al. 2025). In the past 10 years alone, over 1000 wilderness areas were added to the World Database of Protected Areas across many countries in Africa, Asia, Europe, Oceania, North America, and South America (Martin et al. 2025). Globally eight nations including Australia, Canada, Finland, the Flathead Indian Reservation (a sovereign nation within the U.S.), South Africa, Sri Lanka, and Russia have statutory or legally protected 1b wilderness areas, as are found in the U.S., and seven other countries have formally designated wilderness zones with unique rules and regulations (Martin et al. 2025). Each country

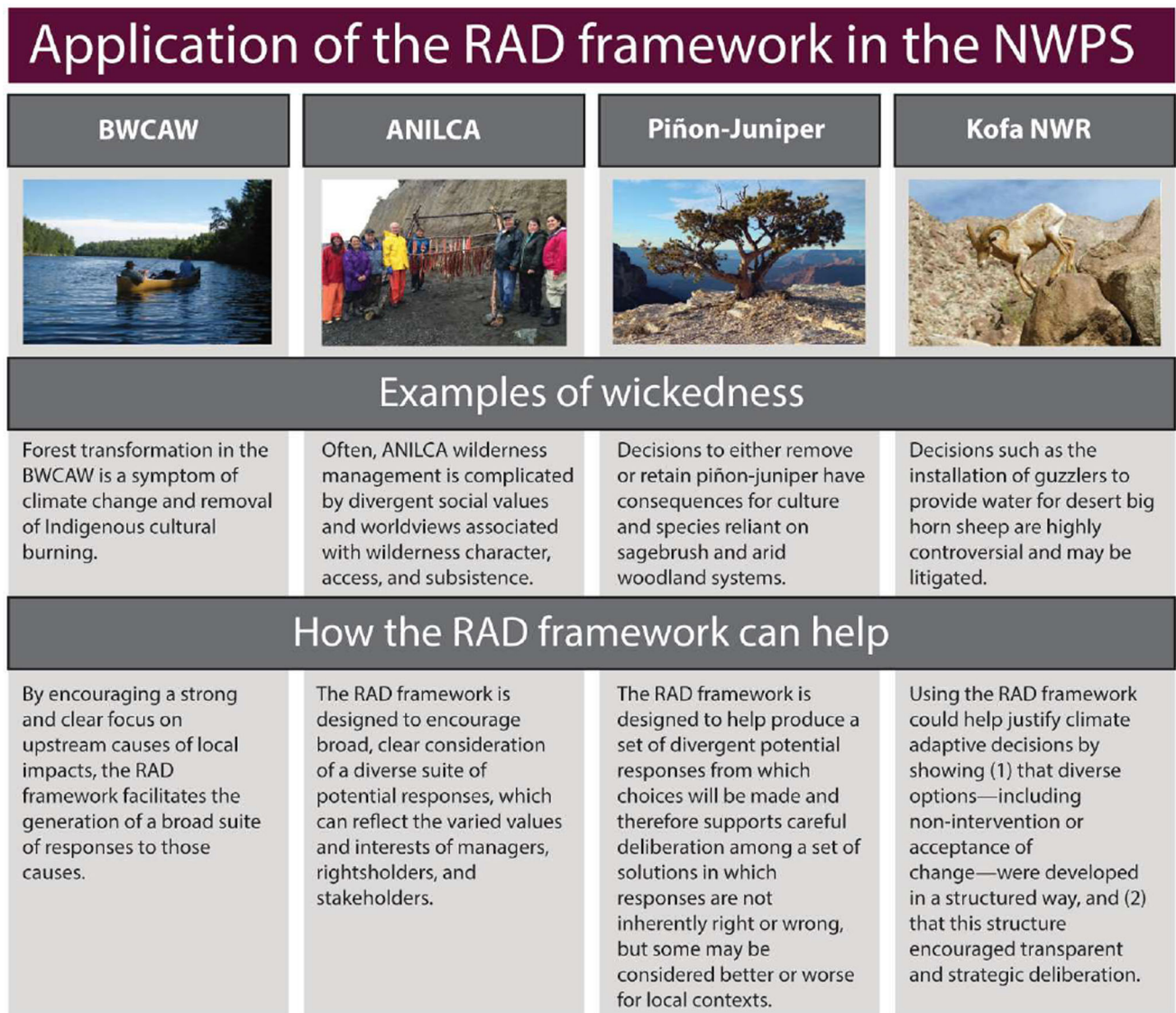


Fig. 7 How the RAD framework can help untangle each critical element of the wicked problem with examples across the National Wilderness Preservation System (NWPS). Photo credits from left to right: USDA Forest Service; Barack Obama; US National Park Service; US Bureau of Land Management

manages and conceptualizes wilderness somewhat differently, but the wicked problem described in this paper is relevant globally. That is, impacts related to climate change may threaten protected areas' "natural character and influence" (Dudley 2008, 14) around the world, and therefore, managers of these places may need to navigate trade-offs between approaches that "let nature be"—as practiced in Germany—and approaches that seek to preserve ecosystem composition, structure, and function (Martin et al. 2025, 40). Furthermore, Natural World Heritage Sites, Biosphere Reserves, and Ramsar Sites often overlap or are adjacent to IUCN category 1b wilderness areas, which may be particularly challenging given these areas are often designated to protect certain

biophysical features in perpetuity (Perry 2015; Kormos et al. 2016; Jones et al. 2025; UNESCO n.d.).¹

CONCLUSION

In summary, managing the impacts of climate change within wilderness poses a wicked problem for wilderness managers. To navigate this wicked problem, we have

¹ In Fig. 7 BWCAW is an abbreviation for Boundary Waters Canoe Area Wilderness; ANILCA is an abbreviation for Alaska National Interest Lands Conservation Act; and NWR is an abbreviation for National Wildlife Refuge

moved theory into practice and illustrated how the resist–accept–direct (RAD) framework can be used to help wilderness managers respond to impacts of climate change. Although particularly acute within the U.S., implications of this wicked problem will likely be felt internationally, and the problems and solutions identified here may be applied by land managers across the world as they steward wilderness through the twenty-first century and beyond.

Acknowledgements This work was partially supported by the USDA Forest Service, the U.S. Bureau of Land Management, the U.S. Fish and Wildlife Service, the U.S. Geological Survey, and the U.S. National Park Service. We thank Peter Landres, Fritz Klasner, and anonymous reviewers for helpful comments.

Data availability This work was not empirical; therefore, there are no relevant data available to share.

Disclaimer Statement This publication has been internally reviewed by the National Park Service and peer-reviewed and approved for publication consistent with the U.S. Geological Survey Fundamental Science Practices (<https://pubs.usgs.gov/circ/1367>). Findings and conclusions in this publication are those of the authors, do not necessarily represent the views of the U.S. Fish and Wildlife Service, and should not be construed to represent any official U.S. Department of Agriculture, National Park Service, or U.S. government determination or policy. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government. This work was supported in part by the U.S. Department of Interior and the U.S. Department of Agriculture, Forest Service.

Conflict of interest The authors have no relevant financial or non-financial interests to disclose.

Ethical approval There was no ethical approval needed for this work as it was not empirical and did not include human or animal subjects.

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Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

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