Navigating Ecological Transformation: Resist–Accept–Direct as a Path to a New Resource Management Paradigm

GREGOR W. SCHUURMAN, DAVID N. COLE, AMANDA E. CRAVENS, SCOTT COVINGTON, SHELLEY D. CRAUSBAY, CAT HAWKINS HOFFMAN, DAVID J. LAWRENCE, DAWN R. MAGNESS, JOHN M. MORTON, ELIZABETH A. NELSON, AND ROBIN O'MALLEY

Natural resource managers worldwide face a growing challenge: Intensifying global change increasingly propels ecosystems toward irreversible ecological transformations. This nonstationarity challenges traditional conservation goals and human well-being. It also confounds a longstanding management paradigm that assumes a future that reflects the past. As once-familiar ecological conditions disappear, managers need a new approach to guide decision-making. The resist–accept–direct (RAD) framework, designed for and by managers, identifies the options managers have for responding and helps them make informed, purposeful, and strategic choices in this context. Moving beyond the diversity and complexity of myriad emerging frameworks, RAD is a simple, flexible, decision-making tool that encompasses the entire decision space for stewarding transforming ecosystems. Through shared application of a common approach, the RAD framework can help the wider natural resource management and research community build the robust, shared habits of mind necessary for a new, twenty-first-century natural resource management paradigm.

Keywords: biodiversity conservation, climate change adaptation, natural resource management, nonstationarity, resist–accept–direct framework

Natural resource managers around the world face an increasingly profound challenge: how to steward ecosystems changing irrevocably under human influence. Longstanding anthropogenic stressors such as land use change, overharvest, pollution, and nonnative species introduction (e.g., Christensen et al. 2006, Bates et al. 2017, Jenny et al. 2020), coupled with the increasingly dramatic effects of climate change (Biggs et al. 2018), are propelling ecosystems rapidly along ecological trajectories beyond the bounds of historical variability. Climate change is a particularly important driver because of both the magnitude of its effects and the fact that it is a change that cannot be reversed within standard natural resource management time frames (Hansen et al. 2013). Because climate change is a substantial shift in a fundamental ecological driver, it brings new and dramatically different ecological possibilities that could be desirable or undesirable. A return to a historical "normal," even if other stressors are eliminated, is often no longer possible. Under current rates of change, for example, temperatures across globally significant (terrestrial) biodiversity areas "are projected to increase by an amount at least twice as great as the current natural variability" in most seasons (Warren et al. 2018, p. 400). Whereas in the past a manager could plausibly mitigate many stressors or their impacts to approximate predisturbance ecological conditions (e.g., via habitat and species restoration, pollution reduction, nonnative species removal), accelerated warming, changing disturbance regimes, and extreme events associated with climate change greatly reduce that potential (Stephenson et al. 2010). Indeed, even preserving heretofore unaltered ecosystems is becoming increasingly infeasible in the face of inexorable change (e.g., Chapin et al. 2009, Folke et al. 2010, Ingeman et al. 2019, Coop et al. 2020, Thomas 2020). Much of the planet faces the prospect of substantial, widespread warming-driven changes in vegetation composition this century even under optimistic greenhouse gas emissions scenarios (Nolan et al. 2018, Berdugo et al. 2020). Over 30% of Earth's animals are projected to lose a substantial portion of their climatic range with warming and nearly half of all birds and amphibians may be highly climate change vulnerable (Foden et al. 2013). In aquatic systems, ongoing warming will exceed thermal tolerance limits for 10%–60% of marine and freshwater fish species in their current habitats (depending on future societal emissions choices; Dahlke et al. 2020). In addition, warming and acidification-induced bleaching are anticipated to convert many of the world's coral reefs to macroalgae and noncoral communities (Mumby et al. 2007).

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Under today's accelerating ecological change, dramatic changes that once occurred every few centuries or millennia now occur within human lifetimes. The result is accumulating changes that alter community composition so profoundly from historical conditions that the change is referred to as ecological transformation. Ecological transformation manifests in multiple unique ways across ecosystems (Lindenmayer et al. 2016), and diverse ecological processes, external drivers, and internal feedbacks govern rates of change (slow, fast, or abrupt; Williams et al. 2021). At its core, ecological transformation is characterized by persistent shifts in multiple components of an ecosystem that are not easily reversed by management actions. The term is increasingly common in peer-reviewed literature (supplemental figure S1) and is defined in many ways and approached from varied perspectives. In the present article, we focus on transformations that represent *the dramatic and effectively irreversible shift in multiple ecological characteristics of an ecosystem, the basis of which is a high degree of turnover in ecological communities* (Crausbay et al. 2021). These changes in community composition alter multiple ecological characteristics including trophic interactions, structure, and function. Changes in these ecological characteristics, in turn, can have complex impacts on social systems through shifts in the ecosystem services that these ecological communities provide (Reyers et al. 2013).

For managers of ecosystems on trajectories toward transformation, resisting ecological change, even where feasible, may require sustained and intensifying efforts (Millar et al. 2007), as well as trade-offs regarding other management objectives. Stream diversions and snow fencing, for example, may delay climate change-induced transformation of a wet meadow into shrubland or forest (via desiccation), but fencing would likely affect other important ecological features and processes (e.g., the stream from which water is diverted or wildlife movement patterns), as well as the human experience of that place. Where or when longstanding management objectives are no longer achievable or become prohibitively costly, managers will no longer be able to meet established societal and stakeholder expectations. Ecological transformations can have important consequences for human communities through changes in the availability, quality, or type of ecosystem goods and services (Millar and Stephenson 2015), which may lead to significant shifts in how individuals or groups use or interact with natural systems.

This new reality poses a fundamental challenge to the foundational assumption of the historical natural resource management paradigm: stationarity. The assumption of stationarity, "the idea that natural systems fluctuate within an unchanging envelope of variability" (Milly et al. 2008, p. 573), is evidenced by widespread reliance on ecological baselines (characterizations of initial ecological conditions) to guide protection, restoration, and other management (e.g., Landres et al. 1999). The US Forest Service's 2012 Forest Planning Rule, for example, is based on the stationarity concept of natural range of variation, in that it states "the plan must include plan components, including standards or guidelines, to maintain or restore the ecological integrity of terrestrial and aquatic ecosystems and watersheds in the plan area, including plan components to maintain or restore structure, function, composition, and connectivity" (§219.8) and defines *ecological integrity* as "the quality or condition of an ecosystem when its dominant ecological characteristics (for example, composition, structure, function, connectivity, and species composition and diversity) occur within the natural range of variation and can withstand and recover from most perturbations imposed by natural environmental dynamics or human influence." Similarly, US Fish and Wildlife Service policies on habitat management in wildlife refuges (USFWS 2002) direct managers to "view the highest measure of biological integrity, diversity, and environmental health as those intact and self-sustaining habitats and wildlife populations that existed under historic conditions" and "consider the natural [or] historic frequency and timing of processes such as flooding, fires, and grazing." This assumption of stationarity has been tenable only at timescales of the last few centuries to millennia, given past climate and ecosystem variations, but has nonetheless successfully guided managers in reversing anthropogenic impacts on ecosystems. However, the assumption of stationarity is increasingly unrealistic in many situations (Thomas 2020). Natural resource managers and conservation practitioners are working in a world very different from that in which most agencies and management traditions formed, and nonstationarity places a manager in a *terra incognita* in which tools and assumptions from the past are increasingly unhelpful and new approaches to address novel climatic and ecological circumstances are urgently needed (box 1; Ordonez et al. 2016).

The tumult of paradigm shift

Thomas Kuhn introduced the term *paradigm* into the philosophy of science in 1962, arguing that scientific change happens episodically in response to observed inadequacies in existing theories (Kuhn 1962, Bird 2018). Building on Kuhn's conception from a psychological perspective, Margolis (1987, 1993, p. 2) defined a paradigm as "habits of mind" shared within a community. Paradigm shifts happen when community members encounter situations or obstacles that cannot be explained or addressed by existing habits of mind, motivating the search for new ways of thinking about or approaching a problem. As new habits of mind become widespread, they eventually coalesce into a new paradigm.

The natural resource management community is currently confronting just such a liminal moment between an established and an emerging paradigm. Conservation and resource management has long focused on maintaining or restoring species and ecosystems, often (as discussed above) with goals defined by "natural" or "historical" baseline conditions (e.g., USFWS 2001, USNPS 2006, Gross et al. 2016) or "ecological

Box 1. Types and rates of ecological transformation.

The diversity of types and rates of ecological transformation (for a review, see Crausbay et al. 2021) is important to understand because it produces a diversity of resource-management challenges and opportunities (Hughes et al. 2013, Williams et al. 2021). A depiction of ecological response to directional climate change over time could take on various shapes (figure 1). Smooth and linear ecological change can either be fast, as in a responsive system that closely tracks environmental change, or slow, as in a system that lags in response and is not in equilibrium with climate change. Nonlinear change occurs in resistant or resilient systems (Connell and Ghedini 2015), which persist largely unchanged in the face of steady environmental change and then change substantially all at once, often in a way that is surprising to managers. Some abrupt ecological changes result from external triggers such as wildfire or drought, and the combined press and pulse of climate change and extreme weather (Harris et al. 2018). Other abrupt ecological changes arise from internal stabilizing processes reaching limits in the face of incessant environmental change (Williams et al. 2021), such as when rates of sea-level rise exceed rates at which marshes and mangroves can adapt by building soil vertically (Kirwan and Gedan 2019). The type and rate of ecological transformation depends on the particulars of the climatic, geographical, and ecological context, and an array of complex ecological processes that are governed partly by contingencies and environmental stochasticity (Jackson and Blois 2015, Williams et al. 2021).

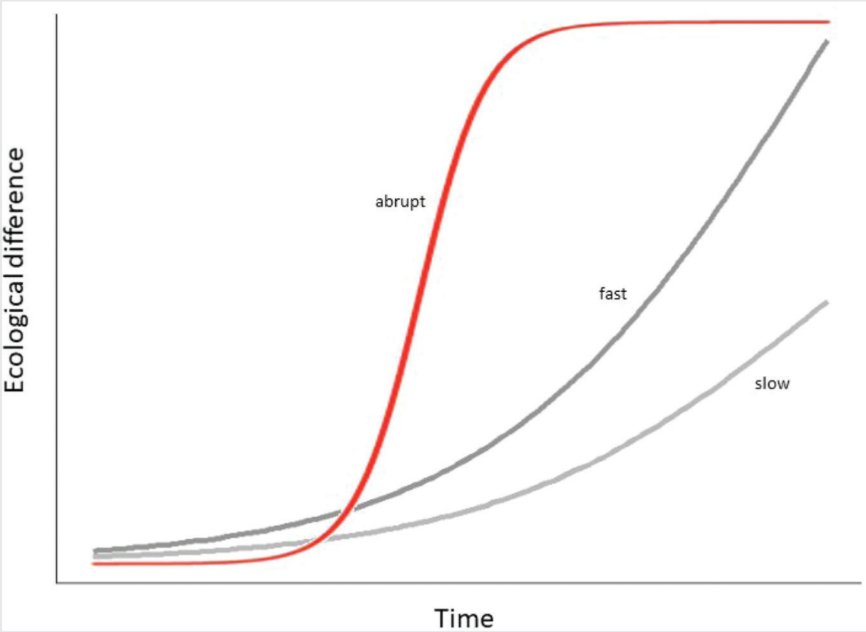

Figure 1. Three broad types and rates of ecological transformation (Williams et al. 2021) in response to intrinsic climate variability and sustained, directional change (i.e., an anthropogenic climate trend). Ecological difference is assessed relative to the initial condition and can be expressed more technically as ecological dissimilarity (Crausbay et al. 2021). A hypothetical, highly responsive ecological system (the dark gray line) responds smoothly to this steady environmental change and quickly becomes a qualitatively different (transformed) system. An ecological system may also respond smoothly but slowly (the light gray line) and may lag behind climate change. In contrast, more resistant or resilient systems (red line) persist largely unchanged amid intensifying climate change until thresholds are crossed (resilient systems) or a large weather extreme or disturbance occurs (resistant systems), at which point they undergo abrupt ecological change.

For example, smooth, fast change is occurring along North America's Atlantic coast, where conversion of saltwater-intolerant upland forest to saltwater marsh proceeds steadily uphill in concert with decadal sea-level trends (Kirwan and Gedan 2019) and leaves ghost forests as persistent, expanding legacies of former ecological condition (figure 2). This steady, relatively predictable change provides opportunities for sustained, calibrated intervention to influence the extent and rate of transformation (Kirwan and Gedan 2019). In contrast, nonlinear change is occurring in formerly forested lands on Alaska's Kenai Peninsula; episodes of drought, bark beetle outbreak, and wildfire are transforming Lutz spruce (*Picea glauca* x *Picea sitchensis*) forest into a novel monotypic grassland (*Calamagrostis canadensis*) that now supports more frequent wildfires. This abrupt transformation into unfamiliar ecological conditions and processes not only raises urgent questions about the nature of the ecological trajectory, but also about opportunities to manage it (figure 3; also see Magness et al. 2021).

Figure 2. Sea-level rise, which is particularly rapid along the mid-Atlantic North American coast, is steadily transforming upland forest to salt marsh on Blackwater National Wildlife Refuge on the Chesapeake Bay. The hardwoods (American sweetgum, **Liquidambar styraciflua***; black gum,* **Nyssa sylvatica***; red maple,* **Acer rubrum***; and various oak species,* **Quercus** *spp.) are the first to succumb to groundwater salinization. Here in the site pictured, most of the more salt-tolerant loblolly pines are dead too, but a few persist. Meanwhile salt marsh species (including cattail,* **Typha** *spp.; chairmaker's bulrush,* **Schoenoplectus americanus***; sedges and nonnative common reed,* **Phragmites australis***) have taken over the former forest floor. Photograph: Matt Whitbeck, US Fish and Wildlife Service.*

Figure 3. Since the late 1980s, a combination of drought, spruce bark beetle outbreaks, and wildfire—each intensified by global warming—has transformed tens of thousands of acres of forest in the Caribou Hills of Alaska's Kenai Peninsula, in the United States, into a monotypic grassland. Whether this new and very different ecological condition is transient or persistent is an important question for managers and stakeholders. In what may be an answer to this question, the Tustumena Lake Fire of 2019 was the first spring lightning-caused grass fire in the hills. Photograph: Jason Jordet, Alaska Division of Forestry.

integrity" (e.g., US Forest Service 2012 Forest Planning Rule [§219.8]; Canada National Parks Act [S.C. 2000, c. 32 (Can.)]). But this emphasis on resisting or reversing human impacts is a poor fit for stewarding transforming ecosystems in a nonstationary world increasingly experiencing new or novel ecological conditions. The inadequacy of this paradigm for solving twenty-first-century resource management challenges is increasingly noted (Choi 2007, Kueffer and Kaiser-Bunbury 2014, Ralls et al. 2018, Prober et al. 2019, Van Meerbeek et al. 2019). Resource management organizations and thought leaders recognize the need to instead manage for "continuous change that is not yet fully understood" (Colwell et al. 2012, p. 19), "manage for change, not just persistence" (Stein and Glick 2014, p. 2), or "shift attention from target states to target rates" (Williams et al. 2021, p. 17).

The challenge is yielding creative dividends: "Driven by the need to find solutions to these emerging challenges, biodiversity conservation is entering a phase of prolific innovation" (Kueffer and Kaiser-Bunbury 2014, p. 131). But it is not (yet) producing clarity. A resource manager seeking advice about how to manage for continuous change instead finds a cacophony of diverse, overlapping, and sometimes conflicting frameworks and typologies (of varying purpose and complexity) for responding to directional change and addressing the challenge of ecological transformation (table 1; also see Peterson St-Laurent et al. 2021). Clear, actionable guidance for strategically stewarding transforming ecosystems (i.e., setting objectives and targets) does not yet exist and, without higher-level conceptual clarity, "there is a genuine risk of the conservation community fragmenting into different schools of thought" (Kueffer and Kaiser-Bunbury 2014, p. 131).

Establishing a new resource management paradigm will require the eventual emergence of a community consensus about the approaches (habits of mind) that address the challenges of conservation in an age of rapid ecological transformation. But natural resource management cannot afford paralysis or endless debate in the face of intensifying global change. Managers need clear, useful guidance now. Developing and implementing such guidance will, in turn, allow the wider natural resource management and conservation communities to start building shared concepts and decision-making strategies that form the foundation for new collective habits of mind.

As familiar ecological conditions change, bringing novelty, surprise, and uncertainty, natural resource managers will require a new approach to decision-making that spans the full range of potential responses to ecological transformation. The resist–accept–direct (RAD) framework addresses this confounding situation. It helps managers make informed, purposeful choices about how to respond to changing ecological trajectories. The RAD framework also lends itself to adaptive management-based approaches (Lynch et al. 2021, USNPS 2021), because it encompasses the entire decision space for responding to ecosystems facing the potential for rapid, irreversible, and directional ecological change.

Responding to ecological trajectories with the resist–accept–direct framework

The RAD framework has emerged over the past decade in recognition of the shortcomings of conventional concepts, such as "naturalness" or historical range of variability, as guidelines for management. Aplet and Cole (2010) first asserted that there are only three fundamentally different management responses to transformational change. Managers can actively resist the ecological trajectory by restoring conditions where change has occurred. Alternatively, they can accept the trajectory, allowing ecosystems to drift into new conditions, often with uncertain consequences. The third option is to intervene in the trajectory so as to direct, guide, steer, or facilitate transformation in ecosystems toward new states intended to be more concordant with emerging climates and better able to sustain biodiversity and desired ecosystem services. Consensus has built around these three contrasting response options, although different terms are sometimes used (box 2; Fisichelli et al. 2016a, 2016b, Aplet and McKinley 2017, Schuurman et al. 2020, Lynch et al. 2021, Thompson et al. 2021).

The RAD framework presents the following options for manager response to an anthropogenic ecological trajectory:

1. **Resist** the trajectory, by working to maintain or restore ecosystem composition, structure, processes, or function on the basis of historical or acceptable current conditions;
2. **Accept** the trajectory, by allowing ecosystem composition, structure, processes, or function to change autonomously; or
3. **Direct** the trajectory, by actively shaping change in ecosystem composition, structure, processes, or function toward preferred new conditions.

In describing these options, we distinguish between intervention, which Cole and Yung (2010, p. 7) defined as "any prescribed course of action that intentionally alters ecosystem trajectories," and *management*, which is a more generic term that includes ecological intervention as well as many other management actions. Interventions involve intentionally manipulating physical and biological conditions—explicit responses to ongoing or anticipated ecological change (Hobbs et al. 2011). Management actions include the entire suite of possible management strategies—from intervention to controlling how much and what types of use can occur in an ecosystem. Management also encompasses interactions with resource users and the public, who may hold a range of expectations about current and future ecological conditions and services in a given area (e.g., Clifford et al. 2021). The distinction between these two important terms is critical because, for example, deciding not to intervene (i.e., to accept) does not necessarily mean deciding not to take any other management actions.

This framework was designed for and by natural resource managers. It focuses exclusively on management response options (i.e., actions) and helps a manager decide whether to intervene in an ecological trajectory to either resist change and maintain past conditions or direct change and guide emergence of preferred new ecological conditions (table 2). The RAD framework contrasts with typologies that mix management actions and desired ecological outcomes of those actions, such as Millar and colleagues' (2007) three Rs (resistance, resilience, and response options) or Peterson St-Laurent and colleagues' (2021) RRT (resistance, resilience, and transformation). In our conception, resilience is not a management response; it is instead an ecosystem attribute that is often but not always desirable (Walker 2020). Resilience can also be constraining because for many it embeds the idea of returning to or maintaining a predisturbance condition (Fisichelli et al. 2016a).

Managers must consider the social, institutional, and cultural realities of transformation alongside the ecological realities (Clifford et al. 2021). Moreover, the RAD framework must be expansive enough to include and reconcile the conflicting natural resource management values and preferences of diverse stakeholders and rights-holders (Kueffer and Kaiser-Bunbury 2014; also see Clifford et al. 2021). One key aspect of such reconciliation is *intentional engagement* with Indigenous knowledges, values, and perspectives, an important area of future work (box 3).

The historical paradigm assumed that biodiversity conservation simply reflects the degree to which nature is protected from human influence. This view of conservation options lying along a one-dimensional spectrum, from protecting historical biodiversity by leaving nature alone to allowing biodiversity to be lost as a result of human activity, is no longer tenable (Kueffer and Kaiser-Bunbury 2014). Given the prevalence of directional drivers of change, the context for conservation action can be described in at least two dimensions. One of these dimensions is intensity of intervention, which is our chosen term for a concept that has also been called freedom from human control (Aplet

Box 2. The evolution of RAD-related adaptation terminology.

The Intergovernmental Panel on Climate Change noted in their 2007 synthesis report that "various types of adaptation exist, e.g., anticipatory and reactive, private and public, and autonomous and planned" (IPCC 2007). Since then, numerous typologies of adaptation strategies and a plethora of terminology have emerged. Magness and colleagues (2011) distinguished between retrospective and prospective adaptation, depending on whether the objective of adaptation is persistence of historical conditions or transition to new conditions. In Climate-Smart Conservation, Stein and colleagues (2014) distinguished between anticipatory actions "that prepare for known or potential future impacts" and reactive actions "that respond to impacts already realized."

Millar and colleagues (2007) were among the first to classify adaptation strategies according to their goals and desired ecological outcomes. They identified three options: resistance, where the goal is "to forestall impacts and protect valued resources"; resilience, where the goal is "to improve the capacity of ecosystems to return to desired conditions after disturbance"; and response, where the goal is "to facilitate the transition of ecosystems from current to new conditions." Subsequently, accepting change has been recognized as a common response that constitutes climate change adaptation if the decision to accept is made with intentionality and not simply by default.

Some typologies of adaptation strategies are based on goals and desired ecosystem traits (e.g., autonomous change), whereas others are based on how managers respond to the ecological trajectory (e.g., accept). Nevertheless, terms from both types of typologies can be mapped to the RAD framework as follows.

Table 1. Diverse typologies of adaptation strategies can be mapped to the resist–accept–direct (RAD) framework.

RAD strategy	Terminology from other typologies
Resist	Resistance options—"to forestall impacts and protect highly valued resources" (Millar et al. 2007, Stephenson and Millar 2011)
	Resist change—"actively resist change through restoration" (Aplet and Cole 2010, Aplet and McKinley 2017)
	Ecosystem maintenance (Magness et al. 2011)
	Persistence of current conditions (Fisichelli et al. 2016a)
	Resist change—"ecosystem transformations can be resisted, because managers choose to promote the persistence of current or historical ecosystem composition, structure, and processes" (Thompson et al. 2021)
	Resistance—"maintain current/historical structures and functions" (Peterson St-Laurent et al. 2021)
Accept	Accept change—allow ecosystems to "drift into new, unprecedented conditions, with unknown consequences for biodiversity" (Aplet and Cole 2010, Aplet and McKinley 2017)
	Restraint—"leave some places alone" (Stephenson and Millar 2011)
	Natural adaptation (Magness et al. 2011)
	Autonomous change—"in which a resource responds to change with no management response intended to drive the system toward a specific state" (Fisichelli et al. 2016a)
	Accept change—"ecosystem transformations can be accepted, perhaps because they cannot feasibly be stopped, they are not sufficiently impactful to warrant a response, they are considered acceptable (perhaps even desirable) by stakeholders or society, or there is a lack of will or impetus to resist change despite sufficient knowledge and resources" (Thompson et al. 2021)
	Autonomous transformation—"facilitate the autonomous transition to new structures and functions" (Peterson St-Laurent et al. 2021)
Direct	Response options—"to facilitate transition of ecosystems from current to new conditions" (Millar et al. 2007)
	Guide change—use "interventions to transform ecosystems into conditions more resilient to future climates, better able to conserve important… values." (Aplet and Cole 2010, Aplet and McKinley 2017)
	Realignment—"facilitate changes" (Stephenson and Millar 2011)
	Facilitate transitions (Magness et al. 2011)
	Facilitate change—"so that inevitable system transitions might retain desirable ecological attributes, rather than result in complete collapse of ecosystem functions and services." (Stein et al. 2014)
	Directed change—"toward a specific new future" (Fisichelli et al. 2016a)
	Direct change—"ecosystem transformation can be directed towards a specific alternative ecosystem configuration, because resisting change appears to be impossible and feasible opportunities exist to steward change towards a more-desirable outcome than that anticipated from accepting the default trajectory of change" (Thompson et al. 2021)
	Directed transformation—"drive transformation toward new structures and functions" (Peterson St-Laurent et al. 2021)

1999, Aplet and Cole 2010), deliberateness of intervention (Kueffer and Kaiser-Bunbury 2014), intervention class (Prober et al. 2019), degree of ecosystem self-regulation (Van Meerbeek et al. 2019), or Heller and Hobbs' (2014) notion of natural practice. Intensity of intervention to successfully resist change will generally increase over time as the ecosystem experiences intensifying anthropogenic stress. The other dimension, deviation from historical conditions,

Table 2. Comparison of resist–accept–direct (RAD) approaches in terms of what each involves, underlying goals and values, and possible motivations for choosing each approach.

Category	Resist change	Accept change	Direct change
How is the approach defined?	Work to maintain or restore ecosystem composition, structure, or function on the basis of historical or acceptable current conditions	Allow ecosystem composition, structure, and function to drift autonomously (away from historical conditions), without intervening to alter the ecological trajectory	Actively shape ecosystem composition, structure, and function to create a new ecosystem configuration on the basis of preferred conditions and ecosystem services
What does the approach entail? (nonexhaustive)	Reduce the magnitude of directional transformative forces (e.g., plant riparian vegetation to maximize stream shading and enhance stream cooling)	Avoid acting to alter the magnitude, trajectory, or ecological outcome of directional transformative forces (e.g., allow sea-level rise to transform freshwater wetlands into saltwater wetlands)	Act to direct the magnitude and effects of directional transformative forces (e.g., extend the head of a tidal creek through excavation to allow seawater intrusion and provide connectivity between emerging and disappearing saltwater wetlands)
	Reduce the risk of severe disturbance (e.g., prescribed burns or forest thinning to reduce risk of severe fire)	Monitor to see what happens, look for unforeseen consequences, and consider the need for active intervention	Direct ecosystems toward a specific condition that differs from the past but is more resistant or resilient to future climatic conditions (e.g., postfire, revegetate with species expected to be adapted to emerging and future conditions)
	Maintain climate change refugia (e.g., protect refugia from nonclimate stressors such as nonnative species invasion and development)	Possibly take management actions other than active intervention (e.g., visitor communication)	Monitor to look for unforeseen consequences and assess whether the ecological trajectory aligns with expectations
	Restore changing ecosystems (e.g., replant historical vegetation and irrigate as needed)		
	Monitor to look for unforeseen consequences and evaluate success and feasibility of resisting		
Desired outcome or goals	Persistence or restoration of historical conditions and services, using a retrospective benchmark	New conditions and services resulting from intentionally not guiding change	New conditions, clearly defined, intentionally sought, and ideally part of a self-sustaining system
		No specific target conditions needed	
		Strategic allocation of finite management resources to other focal areas or issues	
Motivations for each approach	Conserve historical or current conditions	Conserve some ecosystems in an unmanipulated condition	Provide a new set of conditions and ecosystem services preferable to those that would result from either accepting change or seeking to resist change where doing so is futile
	Retain existing or recreate former ecosystem services	Insufficient resources or inability to shape the ecological trajectory	
	Buy time for autonomous species response or further management actions	Desirable ecosystem services are not threatened	

approximates the degree of anthropogenic change—that is, how far society wants to allow future ecological conditions to deviate from those of the past, from pristine to novel (Aplet 1999, Aplet and Cole 2010) or from historical to novel (Kueffer and Kaiser-Bunbury 2014). This dimension parallels the axis that Van Meerbeck and colleagues (2019) refer to as size of the human footprint.

Resisting, accepting, or directing the ecological trajectory is not a spectrum of choices, with one action intermediate between the others, as some have interpreted it (e.g., Peterson St-Laurent et al. 2021). Rather, resist, accept, and direct differ in the two dimensions that together encompass the variable perspectives different stakeholders may hold regarding conservation and managing change—the intensity of intervention and the deviation from historical conditions (figure 4).

See box 4 for an analogy in which resist, accept, and direct are the responses that sailors might take to being driven away from their home port by persistent, directional winds. Importantly, given nonstationarity and directional

Box 3. Indigenous knowledges, values, and perspectives and RAD framework development.

Rapidly changing climate, other modern stressors, and social changes are driving ecological conditions beyond recent human experience and challenging management strategies. In the present article, we bring expertise and perspective from a specific context—a set of assumptions, practices, and norms based on twentieth-century Western science and, in particular, the dominant version of natural resource management in the United States and Canada. This model of science-based management clearly needs significant reexamination given the speed and increasing irreversibility of change, and we propose that the RAD framework can help meet this challenge. It provides a robust approach and encourages conversations about the full breadth of response options before deciding on management actions. However, we also recognize the limits of our own expertise and perspectives, especially regarding Indigenous knowledges, values, and perspectives. To be clear, the discussion thus far regarding the framework has included only limited involvement and input from Indigenous practitioners and experts, who would bring additional insights and perspectives to this evolving conversation (e.g., Panci et al. 2018, Matson et al. 2021).

Indigenous knowledges and stewardship have been in place for millennia, and practitioners have faced a variety of challenges from which sustainable practices have been derived (ICE 2018, Wong et al. 2020). Indigenous peoples have developed deep and integrated knowledge of how plants and animals interact and respond to change (ICE 2018, Wong et al. 2020). And Indigenous peoples have faced transformations in their lifetimes and withstood centuries of colonial violence and, despite horrific disruptions to communities and livelihoods, maintained invaluable knowledges and stewardship practices.

Increasing recognition that modern conservation approaches do not appropriately address Indigenous ecological perspectives and cultural values is meanwhile leading to a shift toward more collaborative approaches to protected area governance (Murray and King 2012). Examples include establishment of Indigenous advisory boards, cooperative management bodies, and shared decision-making and governance (ICE 2018). This model can be seen as a step in the right direction or a misstep, because on the one hand it incorporates Indigenous values into environmental stewardship but on the other hand it does so via integration into colonial structures rather than by building from a base of Indigenous values (Finegan 2018). A growing number of Indigenous Protected Areas around the world represent important opportunities for Indigenous-community-led stewardship and governance, ensuring the protection of Indigenous lifeways and cultural well-being for future generations (ICE 2018).

This growing community of Indigenous stewards, land managers, and conservation practitioners is facing the same unprecedented shifts in climate and ecological systems and engaging in culturally rooted adaptation (e.g., TAMT 2019). Great potential exists to learn from one another as humanity struggles to find solutions for transforming ecosystems and the beings that inhabit them.

We view this publication as a first step and an invitation to further dialogue with a broad range of conservation practitioners—in particular, Indigenous knowledge holders and decision-makers—to develop a broader understanding of challenges and stewardship approaches as we collectively face intensifying global change.

transformative change, options for coincidence of both a low intensity of intervention and low degree of deviation from past or present conditions are dwindling. Recovery or persistence of historical conditions by simply protecting systems from direct human influence is increasingly infeasible (Aplet and Cole 2010). The exception might be refugia in which, by definition, rates of directional transformative change are minimal (Morelli et al. 2016).

The RAD framework is intended to help a manager consider and then choose among resisting, accepting, or directing. All three RAD management options—including accepting change—have a legitimate place in natural resource management. And each, if intentionally pursued in response to climate change effects, constitutes climate change adaptation. These three options collectively describe the entire decision space for responding to the ecological trajectory; there are no other possible responses. That said, numerous pathways may lie between the extremes of exclusively resisting, accepting, or directing change (figure 4). Although resist, accept, and direct are conceptually distinct, they are choices of emphasis and managers can use this portfolio of approaches in a complementary manner (Aplet and McKinley 2017, Magness et al. 2021). Managers might direct some trajectories of change and accept others, perhaps by intervening infrequently rather than chronically. They might encourage persistence of some historical or iconic elements while directing or accepting trajectories of change in others. They might intentionally accept compositional change but not a change in structure or process. Managers might accept the infeasibility of maintaining a particular species assemblage where it occurred historically but attempt to provide for that assemblage (or something close to it) elsewhere, in a location in which emerging climatic conditions are more compatible. They might accept loss of historical fidelity at the local level while maintaining historically occurring biodiversity at a regional or broader level (Stein and Glick 2014, West and Julius 2014). They might foster biodiversity recovery from recent human-driven habitat loss with an emphasis on self-regulating ecosystems by rewilding—that is, expanding space for nature and enhancing biodiversity conservation (including via managed relocation) within even strongly human-influenced landscapes (Svenning 2018). This vision of complementary applications of resist, accept, and direct underscores the importance of landscape-scale collaboration, goals,

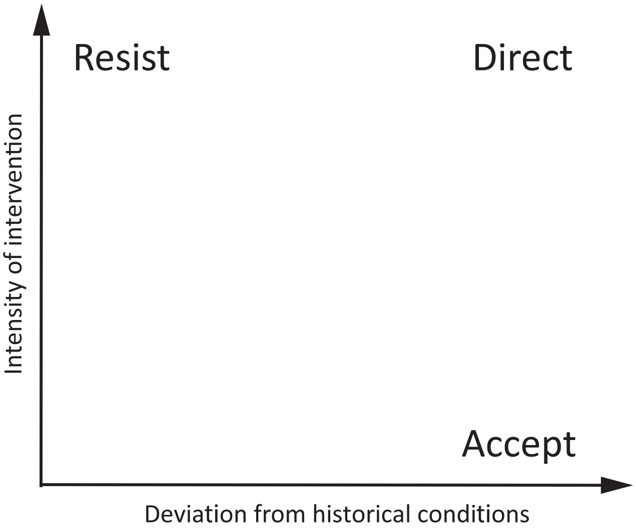

Figure 4. Where strong modern transformative forces are driving ecological change, managers may choose to resist, accept, or direct change. Rather than representing a spectrum, these three options differ in two distinct dimensions: intensity of intervention and resultant deviation of the system from historical ecological conditions. Unless transformative forces are absent, low deviation from historical conditions cannot be maintained with little or no intervention.

and desired conditions (White et al. 2010, Aplet and McKinley 2017, Carter et al. 2020).

Managers can also emphasize different response options sequentially. They might direct the ecological trajectory such that an ecosystem transforms into one that is new and expected to be ecologically resilient and stable. At that point, they might shift approaches from directing change to accepting whatever gradual or small change occurs within the new system. Alternatively, they may find that the new system is less stable than anticipated, in which case they may direct change toward other new conditions. They may shift the emphasis of their approach as management goals and societal values change, as new information becomes available, or as interventions fail under continual stress.

Multiple options may also be applied simultaneously. At Blackwater National Wildlife Refuge, a 12,000-hectare marsh- and wetland-dominated landscape on Chesapeake Bay, Maryland, in the United States (figure 2), managers use all three RAD options to combat change across the refuge (Lynch et al. 2021). Managers have opted to resist change at Shorter's Wharf, an area that contains high marsh habitat, a type preferred by several sensitive bird species including the salt marsh sparrow (*Ammodramus caudacuta*), and the recently Federally listed eastern black rail (*Laterallus jamaicensis jamaicensis*). The refuge uses thin-layer sediment addition to raise the marsh elevation to keep up with sea level rise and areal subsidence. This buying-time resistance strategy complements application of the direct option elsewhere on the refuge in the form of tree removal to encourage tidal marsh immigration into upland forest (box 1; Kirwan and Gedan 2019). The experiment is designed to create high marsh habitat with features that may eventually attract the sparrow, rail, and other species that depend on this habitat type. Finally, much marsh habitat across the refuge is dominated by the nonnative common reed (*Phragmites australis*). Although *Phragmites* can provide storm attenuation and sediment accretion benefits in the marsh, it provides poor habitat for many wildlife species. Managers lack funding to address this crisis, so a strategy of accepting this change is the only option.

Because vulnerability to climate change varies spatially, so should adaptation strategies. Agency or organization missions, stakeholder preferences, and management objectives also vary spatially; management applications will need to vary spatially in response (Clifford et al. 2021, Magness et al. 2021). For example, many national parks contain historic landscapes, endangered species, and designated wilderness. Park managers might resist change to preserve historic landscapes while directing change elsewhere to facilitate establishment of a newly arrived endangered species undergoing range shift. On wilderness lands, however, where, in the United States, allowing the free play of nature is a central goal, managers may choose to accept many of the changes that occur. Pursuing different options in different places can—if the efforts are well coordinated—promote landscape-scale diversity and redundancy and therefore hedge the risks associated with climate change, its biotic effects, and the effectiveness of responses to change (Yung et al. 2010, Magness et al. 2011). A range of options across space also provides a way to address diverse stakeholder values and expectations in responding to changing ecosystems.

Each RAD option supports a different set of desired goals and outcomes (table 2). Given the pace and irreversibility of transformative change, managers will likely need to periodically revisit goals and desired outcomes (Cole and Yung 2010, Stein et al. 2014), as part of a RAD-based adaptive management approach (Lynch et al. 2021). The foremost motivation for resisting change is often to avoid impairment and, if necessary, repair anthropogenic disturbance. Using a retrospective benchmark, resisting change emphasizes retaining existing uses, biodiversity, or ecosystem services, as well as historical continuity—preserving ecosystems so subsequent generations can experience them as previous generations have. As global change intensifies, however, resisting ecological change will likely become more difficult and costly and therefore focused on a more limited number of higher-value sites.

Change may be accepted because of a lack of funding, a lack of concern, or the infeasibility of actively intervening. A more purposeful goal of accepting change is to allow species and ecosystems to respond and adapt to transformational forces as they will, rather than as humans intend. When intentionally accepting change (i.e., for reasons other than

Box 4. A nautical analogy for RAD options.

Consider the analogy of a sailboat at sea being pushed away from its home port by strong winds (figure 5). To accept is to lower the sail and allow the boat to move with the winds, arriving wherever they lead—in this case, potentially either onto the shoreline rocks or safely onto the exposed beach. To direct is to use the winds, via sail and rudder, not to return home as the crew would naturally desire (it is impossible without substantial, motor-powered resistance) but instead to steer the boat to a specific new, preferred destination among available options. Finally, to resist is to lower the sail and fight the prevailing winds, using a motor to attempt to return to home port. Each option differs in terms of costs (energy expended) and outcome.

Figure 5. Resist–accept–direct options for a sailboat at sea. Resist, use motor; accept, allow the boat to move with the winds; direct, use the winds via sail and rudder to steer the boat to a specific new preferred destination among available options. Source: Figure by Elias Miller and Matt Holly.

the inability to do otherwise) the emphasis is on protecting the autonomy of nature to respond; this may be an important value for many, particularly on lands designated as wilderness (Cole 2000), although such designation does not preclude the rationale for selection of either a resist or direct strategy. One inherent challenge in intentionally accepting change is that it is likely not possible to know with certainty (i.e., precision) what will result from accepting change (see Crausbay et al. 2021). In some cases, defining a specific desired outcome may not be possible, in terms of resultant conditions on the ground, and there may be no a priori benchmark. In such cases, managers could consider defining undesired conditions that would trigger a different response strategy (resist or direct).

The goal of directing the ecological trajectory is to facilitate transformation to a new ecosystem condition that is presumably more ecologically stable—better adapted to projected change in climatic and other directional drivers—while providing desired resource uses, ecosystem services, cultural values, or biodiversity benefits even if conditions no longer resemble the past. Using a prospective view, the attributes emphasized by directing change include adaptability and the efficiency of working with, rather than against, the directional forces of change. This approach is particularly important if resultant systems are intended to be self-sustaining for an extended period. The Northern Institute of Applied Climate Science' Adaptive Silviculture for Climate Change network (Nagel et al. 2017) is an example of a replicated, operational-scale experiment that tests the effectiveness of climate adaptation strategies—including using intervention to direct ecological trajectories—in a diversity of forest ecosystem types across North America.

The RAD framework: A practical tool and a building block for a new natural resource management paradigm

The RAD framework is designed to provide a straightforward approach to support intentional, clear, and coherent natural resource management in a rapidly transforming world. It reconciles the diversity and complexity of emerging natural resource management frameworks in a simple, flexible, decision-making tool. In addition, as an organization-neutral construct, it is impartial to mandates, policy, or any other basis for selecting one option over another. With its sole focus on supporting management decision-making, the framework compels purposeful and transparent choices that clearly articulate the underlying rationale for the selected response to the ecological trajectory.

The framing of the three distinct RAD options establishes a common vocabulary for diverse organizations, thereby avoiding a recurring problem of lexical ambiguity in climate change adaptation (Fisichelli et al. 2016a, Siders 2016) and removing barriers that can impede development of a community of practice (Wenger et al. 2002). Coherency in natural resource management across landscapes and larger spatial scales is an urgent need (NASEM 2016). Standard management options described in standardized terms can help resource managers collaborate at larger scales. Therefore, the RAD framework provides both terminology and a common platform that can support collaborative development of joint or complementary adaptation goals and actions across organizations.

The RAD framework also supports and complements established decision support tools and processes. Within or across organizations, familiar criteria remain relevant to determining which of the framework's three options to pursue in a particular setting at a particular time, including organization purpose and mission, stakeholder needs and values, data availability, costs and feasibility, and so on. Therefore, familiar decision-making processes (e.g., stakeholder engagement, collaborative planning) and tools such as structured decision-making, scenario planning, adaptive management, etc.—many of which are undergoing evolution for natural resource management in a nonstationary world (Lienert et al. 2015, Runyon et al. 2020)—may be used in concert with the RAD framework to select, define, and implement goals and actions (e.g., Fisichelli et al. 2016b, USNPS 2021, Lynch et al. 2021, Magness et al. 2021). This integration of RAD with existing decision-making processes and tools can help managers generate creative out-of-the-box solutions and gain confidence in choosing a response.

As managers apply the RAD framework, science that is generated through manager–scientist partnerships and explicitly focused on management-relevant objectives will best support decision-making in the face of uncertain potential outcomes (Kemp et al. 2015), and promote successful adaptive management practices (Lynch et al. 2021). Managers also need new and diverse science to inform RAD-guided management (Crausbay et al. 2021). More extensive collaboration between scientists and managers is particularly important to characterize potential outcomes across the full suite of potential management responses, including the ecological scenarios arising from the decision to accept the ecological trajectory (Crausbay et al. 2021).

Critical opportunities to conserve species, ecosystems, and important ecosystem goods and services lie in action that proactively reckons with the challenges and uncertainties of accelerating ecological change (Stein et al. 2014). This is humanity's reality today and will be for centuries to come. Resource management and conservation is an evolving practice that requires review, revision, and sometimes reversal of decisions in response to new information or changes in societal values (see Clifford et al. 2021). Similarly, the challenge of managing transforming ecosystems will drive evolution in manager and stakeholder expectations and attitudes, monitoring needs, decision-making processes, and other organizational structures or procedures. Transparent and frequent communication between managers and stakeholders—including resource users, surrounding communities, policy makers, and diverse citizens—will be essential.

Natural resource management is not static; management paradigms have evolved as scientific theories and understanding advanced—for example, plant succession and forest management (Clements 1916, Peet and Christensen 1980) or fire ecology and management (van Wagtendonk 2007, Ingalsbee 2017, Young et al. 2020). Similarly, we expect and urge further development of this emerging framework as natural resource managers apply it in a range of settings and integrate evolving insights from transformation science. Through shared application of a common approach, the framework has the potential to help the wider community build robust shared habits of mind with which to respond to transforming ecosystems (Margolis 1987, 1993). The RAD framework is not an endpoint, but a useful guide for managers today. At the same time, we hope it becomes a productive and unifying step toward a twenty-first-century natural resource management paradigm.

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Supplemental material

Supplemental data are available at *BIOSCI* online.

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Gregor W. Schuurman (gregor_schuurman@nps.gov) is an ecologist with the US National Park Service Climate Change Response Program, in Fort Collins, Colorado, in the United States. David N. Cole is an emeritus scientist with the US Forest Service at the Aldo Leopold Wilderness Research Institute, in Missoula, Montana, in the United States. Amanda E. Cravens is a research social scientist in the US Geological Survey's Social and Economic Analysis Branch, in Fort Collins, Colorado, in the United States. Scott Covington is an ecologist in the US Fish and Wildlife Service's National Wildlife Refuge System, in Falls Church, Virginia, in the United States. Shelley D. Crausbay is a plant community ecologist and senior scientist with Conservation Science Partners, Inc, in Fort Collins, Colorado, in the United States; she is also a consortium partner at the US Geological Survey North Central Climate Adaptation Science Center, in Boulder, Colorado, in the United States. Cat Hawkins Hoffman is a supervisory natural resource specialist and program manager and David J. Lawrence is an aquatic ecologist with the US National Park Service Climate Change Response Program, in Fort Collins, Colorado, in the United States. Dawn R. Magness is a landscape ecologist for the US Fish and Wildlife Service, Kenai National Wildlife Refuge, in Soldotna, Alaska, in the United States. John M. Morton is the vice president of the Alaska Wildlife Alliance, in Anchorage, Alaska, in the United States. Elizabeth A. Nelson is a science advisor on conservation and climate change at Parks Canada, in Vancouver, British Columbia, Canada. Robin O'Malley is the retired director of the USGS North Central Climate Adaptation Science Center, and is based in Fort Collins, Colorado, in the United States.