

Responding to Ecological Transformation: Mental Models, External Constraints, and Manager Decision-Making

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Ecological transformation creates many challenges for public natural resource management and requires managers to grapple with new relationships to change and new ways to manage it. In the context of unfamiliar trajectories of ecological change, a manager can resist, accept, or direct change, choices that make up the resist-accept-direct (RAD) framework. In this article, we provide a conceptual framework for how to think about this new decision space that managers must navigate. We identify internal factors (mental models) and external factors (social feasibility, institutional context, and scientific uncertainty) that shape management decisions. We then apply this conceptual framework to the RAD strategies (resist, accept, direct) to illuminate how internal and external factors shape those decisions. Finally, we conclude with a discussion of how this conceptual framework shapes our understanding of management decisions, especially how these decisions are not just ecological but also social, and the implications for research and management.

Keywords: social science, natural resource management, public lands, institutions, conceptual framework

Climate change, often acting in concert with other more longstanding anthropogenic ecosystem stressors, challenges many of the foundational paradigms of natural resource management. Widespread directional changes have or will result in ecological transformations that force managers to question what they are managing for and which “natural” baselines they are evaluating their actions against (Cole and Yung 2010a, Schuurman et al. 2020). Ecological transformation is an extreme type of impact characterized by a significant and irreversible shift in multiple ecological aspects, such as community composition and ecosystem function, rather than a discrete species impact or a temporary ecosystem impact (Schuurman et al. 2020, 2021). Ecological transformation can occur incrementally under sustained and steady pressures—for example, as the consequence of a long-term drought or, more abruptly, in response to a disturbance such as severe wildfire (Bates et al. 2017, Turner et al. 2020, Williams et al. 2020). Although ecological understandings of systems have never been static and although a lag often exists between ecological understanding and management responses, current observations and projections of ecological transformation require

a deep shift in how resource managers understand and approach decision-making.

Modern natural resource management recognizes change as inherent in ecosystems but has, until recently, assumed that change generally operates within familiar bounds or, where it does not, that it operates slowly enough not to warrant a response on human timescales. This assumption of stationarity (i.e., the idea that “natural systems fluctuate within an unchanging envelope of variability”; Milly et al. 2008, p. 573) is poorly suited to a time in which ecological transformations are increasingly common (Biggs et al. 2018). As strategies once considered best practices become less and less effective in this new context (West et al. 2009), the need for new approaches and ultimately for a new management paradigm that fully reckons with environmental nonstationarity is increasingly evident (Schuurman et al. 2021). This departure from the past will require managers to make often difficult decisions and explore a broader range of strategies (Millar et al. 2007, West et al. 2009, Cole and Yung 2010b, Colloff et al. 2017, Young and Duchicela 2020, Lynch et al. 2021).

The resist–accept–direct (RAD) framework emerged in response to this challenge, offering natural resource managers a simple, explicit decision framework to support action

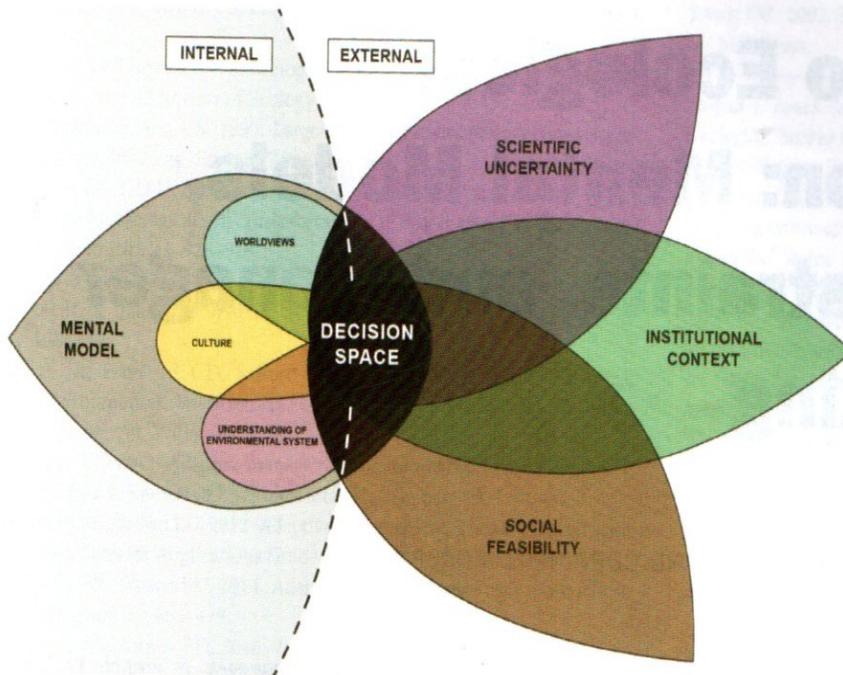


Figure 1. The manager decision space. Their decision space is shaped by a combination of internal and external factors that determine available and favorable alternatives. Importantly, none of these factors are fully distinct and in many cases can overlap or combine.

in the face of dramatic ecological change (Schuurman et al. 2020, 2021, Thompson et al. 2020, Lynch et al. 2021). The RAD framework offers managers three distinct responses to ecological transformation: resisting, accepting, or directing change. As recently formalized by a group of federal agencies in the United States, the RAD framework builds on and refines these options into a tool for management implementation.

Despite growing attention to the ecology of ecological transformation (Carpenter and Brock 2006, Biggs et al. 2018, Turner et al. 2020, Schuurman et al. 2021) and high-level recognition that decisions about responding to ecological change intersect with human values (Millar et al. 2007, West et al. 2009), little attention has focused on the social dimensions of these decisions. More specifically, a more nuanced understanding of how and why public natural resource managers navigate the RAD framework differently and why certain management strategies are selected will carry benefits. Managers presented with the same information about future conditions in the same place often come to very different RAD-type decisions (Clifford et al. 2020), which indicates that these decisions are neither simply objective nor linear responses to data. Ultimately, RAD decisions are judgments made by people, who are influenced by personal, institutional, and cultural factors, requiring a range of social science perspectives to understand how, when, and why decisions are made.

In this article, we seek to illuminate and disentangle the diverse factors that shape RAD decisions by providing a conceptual framework for how RAD decisions are considered and made. This conceptual framework can improve

understandings of public resource management in the face of ongoing or prospective ecological transformation and support increasingly difficult management efforts. We contend that the study of RAD decision-making is an important gap within climate adaptation scholarship and hope that this conceptual framework helps identify key themes and opportunities that other social scientists can explore from a range of theoretical and disciplinary perspectives and across case studies. First, we examine the decision space of public resource managers and describe key internal and external factors influencing management choices, drawing on a wide review of social science literature. Second, we apply our conceptualization of the decision space to the challenge of selecting RAD options, exploring the influence of social, institutional, and cultural factors. We conclude with a discussion of how this conceptual framework and its depiction of the decision space change

our understanding of RAD decisions, exploring important implications for theory and practice of manager decision-making, and resource management more broadly, in an era of transformation.

Natural resource management decision spaces

Natural resource managers' decisions are based on both internal factors arising from their own understanding of a social–ecological system—their mental model—and external forces. These external factors include the perspectives of resource users, surrounding communities, and the public that determine which choices are socially feasible; institutional context created by agency missions, policies, and procedures; and available information, especially the extent of uncertainty related to ecological transformation. Together, these influences form the decision space that managers occupy as they approach a decision (see figure 1).

Decision space is a concept from the public administration and decision analysis fields that describes the set of alternate choices available to someone making a decision. Although some approaches to understanding decision spaces are mathematical (Weirich 2001), we focus in the present article on the concept as used to describe choices available to public managers or decision makers in a decentralized governance system. In this sense, a decision space is defined by the type and amount of choice available, which depends on a combination of formal authority someone possesses and the characteristics or capacities they bring to decision-making (Bossert 1998, Mitchell and Bossert 2010, Bossert and Mitchell 2011, Roman et al. 2017). Decision-making therefore represents an ongoing and evolving negotiation

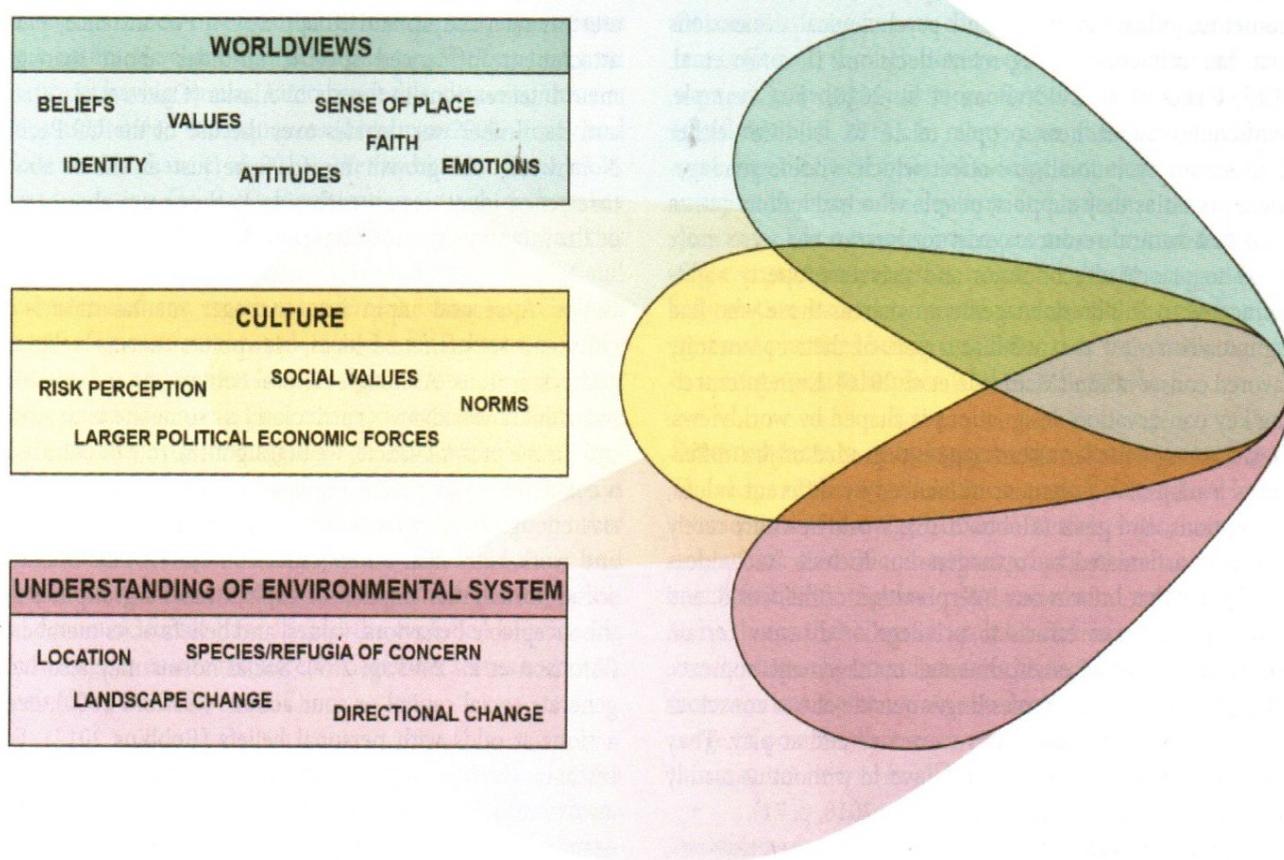


Figure 2. A manager's mental model. The mental model, which represents the internal factors shaping the decision space in figure 1, is composed of influences from worldviews, culture, and understanding of the ecological system.

between an individual's internal orientation and the external constraints they face (Steelman and McCaffery 2011).

In the present article, we focus on the decision space of natural resource managers, whom we define as those professionals formally responsible for making decisions about public lands and waters within a range of institutions and across scales, including land, water, wildlife, natural resource, indigenous, and fire agencies at national, regional, state, and local levels. Although we recognize the important roles played by private landowners, business owners, nongovernmental organizations, and citizens, in the present article, we are interested in ecological transformation in the context of public natural resource management organizations. Given our interest in how the intersection of internal and external factors demarcate the decision space (figure 1), we focus primarily on individual managers' decision-making but recognize that decision spaces may be shared with teams, management units, or agencies.

Mental models: Internal factors influencing manager decision-making

Differences between individual understandings of public lands, resources, and human–environment relationships are well documented by scholars (Krannich and Smith 1998,

Otto-Banaszak et al. 2011, Hajjar and Kozack 2015, Santo et al. 2017, Vinceti et al. 2020). The set of perspectives and experiences that individuals hold about the environment and apply to questions of resource stewardship make up their mental model. *Mental models* are preexisting mental constructs that people use to solve problems they encounter (Denzau and North 1994, Jones et al. 2011). Everyone has a mental model that influences their approach to landscapes, but those of natural resource managers directly influence management decisions and, therefore, shape resource outcomes. Although mental models are unique to individuals, many contain similar elements. We focus on three elements that we argue are particularly important in a manager's mental model: worldviews, culture, and understanding of the ecological system (see figure 2).

Worldviews. Mental models, mental structures that influence how someone responds to situations, are shaped by an individual's life experiences and foundational assumptions about the world. We capture these factors under the category of *worldviews*, although we recognize that by doing so we are simplifying a rich set of categories that could each potentially receive detailed treatment. At the most basic level, worldviews relate “to one's view of the world and one's role and

place in it” (Leashore 1995, p. 112), including core beliefs about human–environment relations. Worldviews include values, attitudes, beliefs, sense of place, identity, faith, and numerous other emotional and psychological dimensions that can influence management decisions (Dvorak et al. 2013, Oakes et al. 2015, Boag et al. 2018). For example, worldviews about how people relate to wildlife—either domination or mutualism—affect which wildlife management priorities they support; people who had a domination view that natural resources exist for human use were more likely to prioritize economics and private property rights in regards to wildlife management, whereas those who had a mutualism view that wildlife is part of their community favored conservation (Manfredo et al. 2016). Even interpreting key conservation designations is shaped by worldviews: Determining whether a landscape is degraded or just different is a subjective judgment influenced by different values, perceptions, and goals (Hobbs 2016). Worldviews are rarely explicitly articulated by managers but include “tacit ideas and beliefs that inform our interpretation of the world, and that may influence efforts to privilege or disavow certain information within environmental management contexts. These ideas and logic frames linger outside of our conscious awareness but are always active, exertive and at play. They structure our understanding of the world without us readily acknowledging their influence” (Simon 2018, p. 71).

Within the many elements that comprise worldviews, we highlight values, identity, and place attachment as particularly important in shaping natural resource management decisions.

Values are “concepts or beliefs about desirable end states or behaviors that transcend specific situations, guide selection, or evaluation of behavior and events and are ordered by relative importance” (Schwartz and Bilsky 1987, p. 551). Values act as “moral principles” (Dietz et al. 2005) that have a significant impact on mental models because they are convictions about the way the world should operate, how oneself or others should behave, and what is right or wrong. Values provide the foundation for attitudes and beliefs. Although disparate attitudes and beliefs are distinct in that they shape people’s day-to-day actions and responses, they also have an important link to the core moral principles that order someone’s life (Feldman 1988, Bidwell 2013). For example, Oakes and colleagues (2015) found that attitudes about new management interventions to protect climate-affected species, including directing the trajectory of ecological change, were associated with different underlying views of whether people were part of or separate from protected areas.

Two additional key components of worldviews that contribute to mental models about landscapes are identity and place attachment, which is a suite of place-related emotions that binds someone to a geographic location (Rubinstein and Parmelee 1992). People often develop place attachment to locations where they work or live; this applies to managers, local communities, and visitors. Identity is frequently tied to place (Raymond et al. 2010), with important implications

for how people understand nature (Clayton 2003). Conflicts and social movements mobilized over resource management issues are often, at their core, about identity and place attachment (Chapin and Knapp 2015). For instance, place attachment influenced specific attitudes about management interventions in forests in Alaska (Oakes et al. 2016), and the timber war debates over the use of the US Pacific Northwest’s old growth forests were just as much about threatened identities on each side as they were about trees or the infamous spotted owl (Satterfield 2002).

Culture. A second input into manager mental models is culture, a set of *shared* ideas, viewpoints, norms, religion, and perceptions. Although cultural context can influence an individual’s worldview (particularly as someone is growing up), in the present article, we highlight the role of culture as a collective set of beliefs, implicit or explicit, that are cohesive enough for members of a social group to communicate and work with each other (Hudelson 2004). This includes social norms, the “implicit or explicit rules a group has for the acceptable behaviors, values, and beliefs of its members” (Aronson et al. 2005, p. 259). Social norms may also help generate social capital or spur actions (Ostrom 2000), even actions at odds with personal beliefs (Robbins 2012). For instance, the pressure of social norms to maintain well kept lawns leads suburban households to use lawn chemicals despite believing that they are dangerous for human and environmental health (Robbins 2012). Similarly, managers may be compelled to act in ways that meet expectations and norms held by their community or professional networks, even if those norms are at odds with their own thinking about the right way to manage a landscape. Furthermore, cultural perceptions can color conservation issues so that they are evaluated and managed on the basis of more than just data; for example, wolf reintroduction and persistence in the US Intermountain West is contentious, reflecting cultural schisms based on shared fears and beliefs (Martin et al. 2019).

Certain species, places, resources, or artifacts can carry religious, spiritual, or cultural importance to communities (Boniface 2013). Climate change threatens many such cultural resources, requiring urgent management decisions about how to adapt with resources that might be irreplaceable and have important implications for heritage (Rockman et al. 2016). For example, for many of the tribes in the US Pacific Northwest, salmon are an important part of ceremonies and rituals, creation stories, and knowledge (National Research Council 1996). More broadly, for many indigenous communities, cultural knowledge, sovereignty, and community practices are linked to place, so a loss due to climate change can carry significant implications (Voggeßer et al. 2013). For these decisions, cultural aspects of management might be an explicit factor in decision-making rather than an implicit factor in mental models.

Political and economic forces are important cultural factors that can shape an individual’s mental model by

influencing which types of value are prioritized, what is considered “beneficial use,” and what are the accepted methods for resource management. For example, the increasing focus on market-based management of natural resources shapes how nature is valued and is leading to solutions that treat nature as having similar, interchangeable elements; this can have unintended consequences (Liverman 2004, Kosoy and Cobera 2010, Lave et al. 2010). Wetland banking, a market-based solution for wetland mitigation, is one such policy that treats wetlands as commodities for trading, but this often ignores the wetlands’ unique physical properties and character and can create management issues, especially in terms of measurement and regulation (Robertson 2004). This and other market-based solutions are part of larger shifts in environmental policies and regulations that have led environmental management to reflect neoliberal logics (McCarthy and Prudham 2004), arguably resulting in a tendency to employ market-based solutions over other alternatives (Bumpus and Liverman 2008, McAfee and Shapiro 2010, Osborne 2015). Others point to the way political economic forces have shaped the evolution of scientific knowledge to ensure resource management serves economic goals (Lave 2012, Sayre 2017).

Understanding of the environmental system. The third input into mental models is how someone understands an environmental issue and its connections within a larger system. People, even those with formal scientific training, build an understanding of their environment drawing on multiple sources of knowledge, including personal experiences of environmental change (Geoghegan and Leyson 2012, Solli and Ryghaug 2014, Hulme 2016, Popke 2016). Land managers, specifically, often build a deep and intricate understanding of their climate and environment through place-based experiences (Brace and Geoghegan 2011, Knapp et al. 2013, Clifford and Travis 2018). By engaging with communities or through membership themselves, managers may also access knowledge developed from collective community experiences in a place, often developed over multiple generations in specific cultural contexts. One type of this collective knowledge held by indigenous communities is Traditional Ecological Knowledge (Berkes 1993, Huntington 2000), which can be a very important source of knowledge for natural resource management (Menzies and Butler 2006). Similarly, resource-based livelihoods such as ranching, that often involve working the same landscape over multiple generations, build a deep and detailed understanding of the ecological system that can provide important insight for managers (Knapp and Fernandez-Gimenez 2009, Knapp et al. 2013).

Knowledge that is produced through formal scientific investigation similarly shapes these understanding. Some environmental systems are hard to know through direct observation; science allows scaling up to see a larger picture (e.g., remote sensing) or scaling down to see things too small for us to sense (e.g., small airborne particles),

or understanding a system completely out of sight (e.g., groundwater). It can also help people to think in different timeframes, either deep in time or projecting into the future. Of course, managers have a hybrid understanding of the system built both through direct experience (or other informal ways of knowing) and more formal scientific knowledge (Goldman et al. 2011). In many cases, these understandings work together; scientific knowledge can shape how people interpret their own observations and influence management decisions. For example, managers who are knowledgeable about ecosystem processes might be able to integrate new information into their mental models and, therefore, management practices before institutional or top-down changes in management take place (Oakes et al. 2016).

External factors shaping manager decision-making

The shape of the overall decision space is determined by the intersection of managers’ mental models with three external factors: scientific uncertainty, institutional context, and social feasibility (figure 1). We understand external factors to be things that allow or prohibit certain actions and ultimately shape the boundaries of the decision space. External factors primarily constrain the decision space, limiting the range of possible choices or potential alternatives, although this may not be true in all cases.

Uncertainty of scientific knowledge. Managers’ decision spaces are constrained by the current state of knowledge about the ecological systems they manage, specifically the unknown. In recognition of this limitation, managers are often charged with using the best available science to inform decisions. But the “best available” standard implicitly assumes that sufficient information exists to guide choices, which may not always be true. In many cases, managers lack information about future or even current conditions (Martin 2019, Kroepsch and Clifford 2021); long-term ecological monitoring can be difficult to fund (Lovett et al. 2007). Managers also lack information at the scale or frequency needed to design management strategies in a changing system (Dilling and Lemos 2011, Archie et al. 2014). In many cases, managers struggle with scientific uncertainty about how climate change might affect their system; this uncertainty can hinder decision-making (Archie 2014). Another challenge with using the “best available science” is that available information may provide conflicting guidance depending on its interpretation (Francis et al. 2005). Managers are often given relatively little direction on how to determine the best choice between two studies (Esch et al. 2018) and no consensus exists on what sources this should come from (Archie et al. 2014). When information does exist, it may be incomplete or not available in useful or usable formats (Cash et al. 2003). Regardless, in an era of ecological transformation and non-stationarity, managers must navigate a “no-analog” future that is dynamic and uncertain (Sample and Bixler 2014) and this uncertainty can constrain which choices are seen as viable.

Institutional context. Resource management agencies are bound by laws, policies, and administrative procedures that require or prohibit actions, shape resource flows, and influence management decisions through a variety of institutional opportunities, obligations, and constraints. Managers report many institutional constraints as barriers in planning for climate adaptation: limited budgets, insufficient staff time and resources, a lack of political will, and others (Archie 2014). For example, in the United States, the mandates of different public land and natural resource management agencies vary significantly, with some placing more emphasis on conservation and others emphasizing resource use (Wilson 2020). Agencies also differ in how centralized decision-making is: For instance, the US National Park Service (NPS) delegates authority and management strongly to its superintendents whereas US Forest Service managers have less autonomy at a local level (Wilson 2020). The “rules” a manager must follow—the laws, policies, and guidelines—restrict adaptation decision-making (Colloff et al. 2017) and these constraints differ by agency. For example, Knapp and colleagues (2020) found that US Bureau of Land Management managers felt constrained by National Environmental Policy Act processes, which slowed down responsive decision-making to annual shifts in forage availability.

Prevailing norms and agency culture are another way that institutions shape manager decisions. Institutional culture differs between public land agencies and even within agencies on the basis of geography, ecosystem, or institutional level (Knapp et al. 2020, Wilson 2020). For example, Page and Dilling (2020) found that organizational worldviews played an important role in adaptation decision-making, particularly whether a climate-related extreme led to organizational change or action. Gosnell and colleagues (2017) found important differences in how US federal agencies approached Section 7 of the Endangered Species Act, with the US Fish and Wildlife Service and the National Marine Fisheries Service in the case of the Klamath Basin issuing separate plans for the same project that undermine each other. Similarly, managers in different institutional settings were shown to have divergent opinions about whether it was appropriate to intervene in wilderness areas, with one study suggesting that managers at the NPS were more in favor of such actions than managers from other federal agencies (Lieberman 2017).

Social feasibility. It is not just managers who have a mental model that guides how they approach and respond to their natural environment. Resource users, surrounding communities, and the public also hold mental models that shape how they understand natural resources and influence how they think those resources should be managed. For instance, resource-based livelihoods are directly affected by natural resource decisions and this relationship with the environment imparts strong beliefs and attitudes about what management decisions are ethical or tolerable (Turner et al. 2014). Of course, these stakeholders’ mental models vary

significantly and are often at odds with each other, pointing managers toward opposite actions (Yung et al. 2003). One emerging influence on stakeholder opinion on transformation is that many are mourning the loss of important landscapes, ecosystems, species, or landmarks affected by climate change. Climate-related losses can manifest in an intense “ecological grief”, with corresponding mental health impacts (Consolo and Ellis 2018). This grief may be particularly strong in communities with resource-based livelihoods or strong cultural ties to the natural environment (Marshall et al. 2019).

Expectations held by stakeholders and the public can be an important external factor in decisions, sometimes playing out in administrative and legislative processes and even in lawsuits. Opposition from stakeholder groups advocating for different management approaches shapes what is “politically possible” (Wilson et al. 2018) and is a documented barrier for managers trying to implement climate adaptation on public lands (Archie 2014), especially for transforming landscapes (Standish et al. 2013). Individuals in land-based livelihoods often depend on public lands to make a living and can feel strongly about decision-making that is unresponsive to changing environmental conditions (Knapp et al. 2020). Landscape changes associated with ecological transformation often create tension between the new ecological reality and social expectations for landscape functions or uses (Clement and Standish 2018). In wildfire management, for example, public and political pressure for aggressive fire suppression tactics is an important influence on management decisions and often limits managers’ abilities to use a broader set of tools (Canton-Thompson et al. 2008).

Making a RAD decision

Together, internal and external factors create a decision space within which managers evaluate alternatives and make choices. Understanding how and why managers navigate RAD decisions differently (see Clifford et al. 2020), requires understanding how mental models and external constraints interact to produce the boundaries of what is feasible in each setting. The RAD framework delineates all possible options—resisting, accepting, or directing—for responding to ecological change. A key tenet of the RAD framework is explicit consideration of all three options in light of desired future conditions, rather than a default to previously used practices that typically revolve around resisting change. Because the RAD framework asks managers and stakeholders to evaluate and choose preferred alternatives from a range of plausible future ecological states, the RAD decision space cannot be separated from the internal, external, social, cultural, and institutional factors influencing individuals’ decision-making.

Each RAD strategy reflects a specific relationship between management and change (table 1). A *resist* strategy seeks to impede an ecological trajectory and prevent ecological transformation and often represents a recommitment to existing management practices, values, and institutional

Table 1. Description of resist, accept, or direct strategies in relation to historical management.

Strategy	Relationship with historical management	Example
Resist	Aligns closely with historical management paradigms that attempt to control change and maintain stability.	Restoration (Aplet and Cole 2010)
Accept	Aligns with historical management in some contexts (e.g., wilderness) but departs in other contexts (e.g., invasive species management).	Wilderness management (Cole 2000)
Direct	Departs from traditional management by seeking to steer transforming ecosystem toward future desired conditions.	Assisting the establishment of better adapted species (Millar and Stephenson 2015).

norms (Parker et al. 2000, Millar et al. 2007). It is closely linked with restoration as it often still carries the goal of returning ecological conditions to a historical baseline or “natural” state (Aplet and Cole 2010, Hobbs et al. 2010, Cole and Yung 2010b, Stephenson and Millar 2012) or maintaining a historical range of variability (HRV; Keane et al. 2009). An *accept* strategy allows an ecological trajectory to proceed without intervention and ultimately may lead to ecological transformation. When accepting an ecological trajectory, managers do not attempt to steer a system toward particular conditions. In this case, the manager is open to new futures that depart from historical conditions. Unlike resisting, accepting does not involve managing toward a specific goal and allows autonomous change to occur and flexibility in outcomes. In some cases, a manager may choose an accept strategy in recognition that it will result in desirable conditions that meet their goals. A *direct* strategy actively steers the ecological trajectory toward a new set of ecological conditions that depart from historical baselines. This decision is based on a recognition that resisting the ecological trajectory may be untenable (Millar et al. 2007, Cole and Yung 2010a, Millar and Stephenson 2015, Aplet and McKinley 2017), but unlike accept strategies, direct strategies are oriented around steering systems toward particular preferred conditions.

Each strategy carries benefits and trade-offs among future ecological conditions, resulting ecosystem services, and stakeholder needs that the manager must evaluate and weigh (Truitt et al. 2015). On the basis of their individual mental models, managers hold distinct and sometimes divergent views about what type of intervention is wrong or right (Yung et al. 2010, Landres et al. 2020); therefore, nonstationarity and ecological transformation raises normative questions that cannot be answered with more ecological data (Clement and Standish 2018). These dilemmas move beyond the technical and scientific realms or questions of feasibility (Lynch et al. 2021). Instead they are ethical (Landres et al. 2020), with consequential outcomes, and they require value-based decisions (Cole and Yung 2010b). Every management decision (including deciding to accept the ecological trajectory and its outcome) will benefit some and disadvantage others (Robbins 2011, 2014, Wyborn et al. 2016). (Note that even the choice to avoid or delay an explicit decision is in effect a decision to allow and, therefore, to “accept” change.)

The RAD framework presents all three RAD strategies as equally legitimate options, leaving managers to consider

context and weigh trade-offs to select which is best for their local landscape. To illustrate the role of social factors in weighing trade-offs, we map how each of the four components of the decision space could lead managers to select different desired future conditions, and different RAD strategies to get to them, in the face of a given management challenge. We examine how each of the four factors might shape a RAD decision and give an example (either real world or hypothetical) for each combination.

How mental models influence RAD decision-making. Given how they shape managers’ approach to environmental challenges, mental models play an important role in mediating how environmental change is understood, particularly in the case of transformational change. Underlying beliefs, values, and attitudes about how people relate to nature will influence the extent to which managers favor intervention to respond to change or accept it, or similarly if they believe directing change is appropriate. For example, given the same information about change, mental models led some managers to interpret ecological change as unprecedented and others to view it as part of system variability; this leads managers to select different RAD strategies (Clifford et al. 2020). Differing beliefs about human–environment relationships also determine how managers interpret a key management concept, such as “naturalness”, in light of ecological transformation (Cole 2000, Aplet and Cole 2010, Cole and Yung 2010b). Divergent interpretations of naturalness may guide which RAD strategy a manager deems most appropriate for their context. Sometimes beliefs about peoples’ role in nature can manifest in contradictory ways: A public survey in western Canada indicated that the respondents who were most worried about the threat of climate change were also least likely to support direct strategies because they viewed intervention as high risk and inappropriate (Hajjar and Kozak 2015).

In this way, mental models will mediate RAD decisions by shaping perspectives on what is right and how to evaluate risk. These are both subjective assertions significantly influenced by an individual manager’s worldviews, environmental understanding, and cultural context (table 2). For example, a study of wilderness managers showed a range of perspectives about whether it is appropriate to intervene in Wilderness Areas, in part because of different worldviews (Lieberman 2017). Research suggests that conservation

Table 2. How mental models might influence decisions to resist, accept, or direct change.

Strategy	Mental model influence on decision	Example
Resist	If their understanding of stewardship focuses on preventing environmental change, managers may view landscapes that maintain historical conditions as “natural” (Aplet and Cole 2010) and therefore desired.	Saguaro National Park was established to protect the saguaro cactus. Managers therefore resist shifts in disturbances that threaten this species wherever they can (see www.nps.gov/sagu/index.htm).
Accept	Managers may be motivated to accept changes by an interpretation of “natural” that means little to no interference (Aplet and Cole 2010) and a larger worldview that understands people as separate from nature (Oakes et al. 2015).	Wilderness areas are required by law to remain “untrammeled,” but this term is not well defined. Some managers may interpret this to mean it is inappropriate for them to intervene and therefore opt for a hands-off approach (Cole 2000 Landres 2010).
Direct	A manager may prioritize maintaining structure and function over preserving specific ecosystem components. Furthermore, when managers have already observed significant transformation themselves, they may feel like they have little choice (Clifford et al. 2020).	Managers, aware that many historically occurring species are not well suited for emerging and projected climatic conditions, respond to an intense fire and concerns about long-term impacts to water quality by replanting regionally native species likely to do well under those conditions. ^a

^aHypothetical example.

Table 3. How social feasibility might influence decisions to resist, accept, or direct change.

Strategy	Social feasibility influence on decision	Example
Resist	The public may be especially attached to certain species or landscapes and resistant to changes to them. This is particularly likely to be the case with iconic features or species. This attachment might influence managers to resist change in those contexts.	Citizens value glaciers persisting in Glacier National Park as they are part of its namesake and therefore may want managers to go to great lengths to maintain them (see Senese et al. 2020).
Accept	The public may accept even unfavorable changes on a landscape if they appear “natural” or not due to intervention or management. This might make it easier for managers to accept change.	The public is willing to accept a massive disturbance that kills a forest if it comes from a pine beetle outbreak or wildfire rather than logging practices. ^a
Direct	The public may accept directing change if such intervention also fosters important (new) ecosystem function or valued resources. This might make it easier for managers to choose to direct change.	An endemic species in Hawai’i is threatened because of transforming conditions that decrease habitat. The public cares about this species and therefore accepts managers’ efforts to save it from extinction by moving it to another island, outside of its native range. ^a

^aHypothetical example.

experts are changing their minds about interventions: Interventions once considered taboo are now increasingly accepted (Hagerman and Satterfield 2014). This illustrates that mental models are always evolving as people learn and incorporate new information (Jones et al. 2011), so over time they will change as ecological systems transform.

How social feasibility influences RAD decision-making. RAD decisions will be influenced by the opinions of resource users, surrounding communities, and the broader public, like any other decision about managing public lands or waters, but determining how to manage transformative change will likely be polarizing and highly consequential. How transforming ecological systems are managed may be particularly contentious because managers’ responses (i.e., selected RAD strategy) can upset current social dynamics and power relations. Every RAD decision affects ecological systems in ways that will negatively affect some people and benefits others. With shared resources, managers are required to weigh trade-offs and navigate challenging decisions on behalf of many stakeholders. For example, accepting or directing change may lead to a loss of resources that are valuable economically, culturally, recreationally, or in other ways.

At the same time, new conditions might be preferable for certain populations. For example, directing a dying forest to a grassland might provide increased grazing opportunities or expanding forests through managed relocation (Schwartz et al. 2012) might expand the habitat of endangered species. Because the stakes of these changes can be high, stakeholder support or resistance may significantly influence management decisions (table 3). As transformations progress and new information becomes available, preferences of stakeholders will likely evolve and shift as well, which means that what is socially feasible today might look different in the future (Yung et al. 2010, Findlater et al. 2020).

How institutional context influences RAD decision-making. The institutional context within which a manager works will influence which RAD decision they select. Because non-stationarity and ecological transformation are largely new management challenges, some RAD strategies might be constrained to a greater degree by institutional practices designed to manage within a historical range of variability. Laws, policies, and administrative procedures create a set of conditions that might promote certain strategies and limit others (table 4). For instance, resisting change has been a

Table 4. How institutional constraints might influence decisions to resist, accept, or direct change.

Strategy	Institutional context influence on decision	Example
Resist	Natural resource management institutions often do not support experimentation and are more likely to support historical models and paradigms. This culture and the processes, rules, and forms required by agencies make it difficult to experiment with new approaches and therefore promote historical practices.	Managers continue to resist change to a threatened population even if the costs are high and they do not think it will be successful. They do this because change threatens an endangered species they are required to protect. ^a
Accept	A manager may not have the resources for resisting and finds that not intervening is more feasible than trying to direct change because of the numerous rules and guidelines. They feel that accept is a lower risk because it does not require them to make contentious decisions.	Managers accept change because they have reached a point where it might be infeasible to do the intensive interventions needed to resist change because of a lack of labor and budget limitations (Millar et al. 2007).
Direct	A manager has resources that might be enough to direct an ecosystem to a new self-sustaining state, but not enough to use for prolonged resisting. Or they feel that the only way to manage a landscape for its mandated purpose (e.g., timber, ranching, recreation) is to direct.	Managers introduce a new game species to be able to maintain hunting on a landscape that can no longer sustain species that were historically hunted. Directing allows them to maintain an important natural resource use. ^a

^aHypothetical example.**Table 5. How scientific uncertainty might influence decisions to resist, accept, or direct change.**

Strategy	Scientific uncertainty influence on decision	Example
Resist	With high levels of uncertainty about future conditions and when or how ecosystems will transform, managers with a low risk tolerance feel they do not have enough information to shift their management.	Available information cannot predict every consequence of managed relocation of species. Many argue that we do not know enough to anticipate all the impacts of introduction (or directing) and the best course of action is to try to resist change until more information is available (Maier and Simberloff 2016).
Accept	The uncertainty about future conditions and how landscapes will transform leads managers to delay action and to accept change until they have more information.	Information is inconclusive about the future conditions and ecological dynamics. Managers feel it would be irresponsible to direct to a new set of conditions with high levels of uncertainty, making accept somewhat a default choice (Truitt et al. 2015).
Direct	Although there is uncertainty about specific climate impacts, managers already can see clear trajectories and fill in knowledge gaps by looking at analogous cases elsewhere. In cases where managers can anticipate change and ecosystem response, they feel confident directing.	Scientific studies show that tortoises can play important roles in grazing and seed dispersal, so managers decide to introduce the Aldabra Giant Tortoise to the Mauritian Islands to replicate an extinct tortoise and improve ecosystem functioning (Griffiths et al. 2010).

strategy long employed by resource managers, so institutions may support this type of strategy by providing needed funding or requiring that managers use historical baselines or preserve historical conditions. Directing an ecosystem's trajectory in response to climate change, on the other hand, is a much newer strategy in many agencies and predicting how direct strategies will align with laws and guidelines might be challenging or unknown, because so few cases have been documented (Stephenson and Millar 2012, Schuurman et al. 2020). For example, the Wilderness Act in the United States requires that land remain untrammeled, but managers and researchers are unsure what that means in the context of transformation, and different interpretations or readings of the law lead to different ideas (Stephenson and Millar 2012, Lieberman 2017). Of course, institutions are not immutable (Mahoney and Thelen 2009, Michelotta et al. 2017). It is likely that institutional context—and the rules, policies, and procedures shaping RAD decisions—will evolve in response to changing political priorities, changing public opinion, and evolving scientific understanding. Therefore, over time some of the constraints may shift, leading to corresponding shifts in the feasibility of RAD strategies.

How scientific uncertainty influences RAD decision-making. Although management decisions in an era of climate change will always be steeped in uncertainty, ecological transformation presents new levels of decision-making uncertainty and difficulty. In addition to uncertainty about how ecological systems will transform, and their cascading impacts, the speed and scope of change, the magnitude, and the type of change (incremental or abrupt; Crausbay et al. 2021), managers also face uncertainty regarding the consequences of different RAD decisions. Managers often report that even with concerns over a threat, they cannot intervene without greater knowledge (Archie 2014, Hajjar and Kozack 2015). For instance, will management efforts to direct change to a new system that can operate in new climate conditions become self-sustaining and largely function independently or will managers need to continue to intervene and tweak the system? Or, how well can managers anticipate the outcomes of different strategies? Are there important unintended consequences? And, how will resource users, adjacent communities, the public, and other stakeholders be affected by different RAD decisions? This uncertainty will undoubtedly shape which RAD decision a manager

selects (table 5). However, over time we might expect to have decreased uncertainty in some or all of these arenas as we observe more RAD decisions and their outcomes.

Conclusions

Examining RAD decisions through the lens of these four factors highlights that there is no single correct way to manage transforming ecosystems; all decisions are context specific, nuanced, and bounded by a range of internal and external forces and constraints. Although all natural resource management decisions are influenced by these factors, RAD explicitly emphasizes consideration of trade-offs in decision-making. Our conceptual framework (figure 1) highlights how these trade-offs and the resulting consequences are social, cultural, and institutional, as well as ecological. RAD decision-making will differ on the basis of the individual making the decision, the institutional context, uncertainty, geography, and larger system they work within, for the reasons explored above. This conceptual framework helps to highlight and shift our thinking around natural resource decision-making and provides a more comprehensive context for understanding it.

Currently discussions of response to ecological transformation focus primarily on changing ecological conditions and only superficially on social conditions (Millar et al. 2007, Young and Duchicela 2020, Lynch et al. 2021). However, to fully understand and support RAD decision-making, we must recognize the same dynamism in social systems that we acknowledge in ecological systems and explore how ecological and social systems interact (Colloff et al. 2017).

Natural resource management decision-making has always included social influences (Backstrom et al. 2018), but in the context of ecological transformation and the profound consequences it carries, these elements are increasingly critical to acknowledge and navigate. Our conceptual framework illuminates a manager's decision space and provides a structure to recognize all RAD decisions as ecological *and* social, and critically intertwined. Even the decisions that appear fully in the technical or scientific realm and purely ecological, such as calculation of stocking rates (Sayre 2017), are still influenced by social factors and value laden (Katz 1992, Landres 2010). RAD decision-making requires subjective judgments about what constitutes the best sources of information, which management goals can or cannot be compromised, what type of values associated with ecosystems are most important, and even which alternatives or choices are considered. For example, there is not an objectively "correct" decision between focusing on an individual endangered species or focusing at a system level. Nor is there a correct answer regarding which pieces of a system can be lost or degraded, which resources should be prioritized, or where loss or degradation might be permissible.

By acknowledging and reflecting on the internal and external factors that influence natural resource decision-making, we may be able to move forward in a more honest and responsive manner. Explicit recognition of and

reflection on social factors that influence decision-making may allow managers to share decision-making processes across jurisdictional and ecological boundaries. This may allow for individual and collective learning (Heikkila and Gerlak 2013) and questioning of assumptions, which could lead to shifts in mental models, social feasibility, institutional context, or research prioritization. By sharing the full suite of factors that influence decision-making, managers may become more aware and self-reflective about factors that are influencing their decision-making and more active in shifting those factors. We urge managers and ecologists to recognize that even decisions we often categorize as ecological or technical are still imbued by external constraints and shaped by mental models. This recognition may create space in decision-making for individual and organizational self-reflection (Schon 1991), which could accelerate the process of adapting decision-making to changing contexts. For instance, if it is clear that a lack of social feasibility is inhibiting decisions that would have long-term benefits for ecosystems, management efforts may shift to public forums to create better dialogue and mutual learning around proposed actions.

It is not just the managers—and their decision spaces—that are changing, but also the nature of their work. Their jobs are changing as landscapes and community perceptions shift and they are required to navigate a slew of new consequences, meaning that managers are experiencing transformation on multiple fronts. For instance, in addition to shifts in ecosystem structure, managers may also face increased demand for public engagement as management decisions become more challenging to and can have a greater impact on the public (Magness et al. 2021, Pelai et al. 2021), and calls for increased attention to and engagement of minorities and underrepresented communities that have been historically marginalized in conservation and natural resource decision making (Finney 2014, Davis 2019, Bailey et al. 2020). These changing environments suggest the need for new skillsets, training, and types of roles for public land managers (Schwartz et al. 2017). Furthermore, it highlights the importance of recruiting diverse managers to make RAD decisions who can draw on a wider set of experiences and cultural values (Foster et al. 2014, Bailey et al. 2020, Yitbarek et al. 2021). This could eventually include shifts in traditional natural resource management training programs, job criteria, and rethinking the types of positions and organizational structure of resource management agencies.

We invite other social scientists to help us empirically test this conceptual framework to refine it with real world case studies of managers grappling with and responding to ecological transformation. Managers do not only make a single RAD decision; they face a series of RAD decisions. Although others have acknowledged the importance of feasibility (i.e., external factors) in RAD decision-making, it has been treated statically, as though feasibility will remain the same for successive decisions (Lynch et al. 2021). It can be expected that *both* internal and external factors will

continually evolve over time to reconfigure and reshape the decision space. As managers increasingly observe ecological conditions that are at odds with their management goals and see traditional strategies fail, they will begin to edit their mental models through learning (Pahl-Wolst 2009). Similarly, external constraints tied to public opinion, scientific uncertainty, and institutional rules will evolve over time as pressures from ecological change continue and previously reliable strategies fail; this change may be slow and gradual, or, like ecological transformation itself, it may happen more abruptly. Importantly, the ways the components of the decision space change will have divergent impacts on each RAD strategy; attending to the way these factors evolve and alter RAD decision-making is an important area of inquiry. For example, how might constraints interact over time? How might feasibility be different for abrupt versus incremental transformations? How does individual and social learning change management decisions?

Furthermore, it is critical to give more thought to the different social outcomes of RAD decisions. Each strategy not only results in a set of ecological conditions but also different social consequences that will have divergent impacts on the many resource users, adjacent communities, the public, and other stakeholders who rely on, use, and enjoy natural resources. What are the impacts? Who are the winners and losers? How do different strategies produce different social outcomes? How can the RAD framework better incorporate or engage with equity?

By explicitly considering the factors that influence decision-making, managers can reflect on shifting values, and reconsider their inherent assumptions about change and natural resource management. These reflections can assist in individual and organizational revision of core assumptions, adaptation of policies and institutions, and more responsive adaptation to shifting contexts. Recognizing the importance of these factors may also lead managers to be more transparent with stakeholders and their colleagues about how they weighed competing visions and priorities and why certain decisions were made (Landres et al. 2020).

It will be important to evaluate equity and justice components of these decisions as well. Conservation and natural resource management has had an often troubled history with marginalized communities, with parks and other protected areas forcibly removing Native Americans (Burnham 2000), creating “white spaces” that excluded African Americans (Finney 2014, Davis 2019), and not being accessible for minorities or other underrepresented communities (Weber and Sultana 2013). Equity, inclusion, and justice could be facilitated through conversations within and across management units, formal tribal consultation, or collaborative processes with stakeholders. Although this was not the focus of this article, it will make more iterative and self-reflective management necessary to avoid inequitable outcomes.

Although we hope this conceptual framework of managers’ decision spaces will inspire future research among social scientists and interdisciplinary teams (also see Crausbay

et al. 2021), even its present form has important implications for resource management and specifically for efforts to apply RAD decisions around the world. Managers cannot separate the social from the ecological nor think about the social dimensions solely as stakeholder engagement or outreach to be conducted after a decision is made. Instead, ecological transformation requires an integrated approach to management. Management decisions have never been purely ecological, but awareness of and reflection on the social contexts of decision-making is critical in the context of ecological transformation.

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