Innovation in Climate Adaptation

Harnessing Innovation for Effective Biodiversity and Ecosystem Adaptation

National Wildlife Federation
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IUCN
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Cover: Whitebark pine *(Pinus albicaulis)*, a keystone species of high-elevation western mountains, is in serious decline due to climate change and other factors. Experimental plantings outside the species' historical range are helping determine the potential for managed relocation, or "assisted migration," as an adaptation strategy. Photo: seed collector, Jasper National Park, Canada. Credit: Iain Robert Reid/Parks Canada.

Title page: Corals are the focus of a variety of experimental adaptation approaches, including identification of thermal-tolerant strains for use in reef restoration, as well as research into accelerated or "assisted" evolution for selective breeding. Photo: Coral restoration nursery, Florida Keys. Credit: Mitchell Tartt/NOAA.

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Addressing the intertwined climate and biodiversity crises demands greater ambition, creativity, and innovation in the practice of climate adaptation. Photo: Green sea turtles (Chelonia mydas) *and masked boobies* (Sula dactylatra), *French Frigate Shoals. Credit: Mark Sullivan/NOAA.*

Executive Summary

Climate change poses growing risks to species, ecosystems, and people, and is challenging many of the assumptions that underpin modern conservation practice. As climate impacts accelerate, conventional conservation approaches are being compromised and losing their effectiveness. As a result, there is an urgent need to not only center climate adaptation in conservation policy and practice, but for adaptation responses to be bolder and more innovative.

Innovation in Climate Adaptation is designed to address this need by promoting creativity and innovation in the practice of climate adaptation for biodiversity and ecosystem conservation. The guide is not about promoting innovation for the sake of innovation; rather, it is intended to help policymakers, researchers, and resource managers harness the power of innovation to achieve more effective adaptation outcomes.

An Innovation Imperative

Although focused on biodiversity conservation and natural resource management, the guide draws extensively on applications and lessons from other communities, particularly the business and technology sectors. Because the term innovation is so widely used—and overused—it is important to clarify what it means and how it should appropriately be applied. For our purposes, innovation can be considered to have three key attributes: *novelty*, *value*, and *process*. Accordingly, in the context of biodiversity and ecosystem adaptation we adopt the following definition:

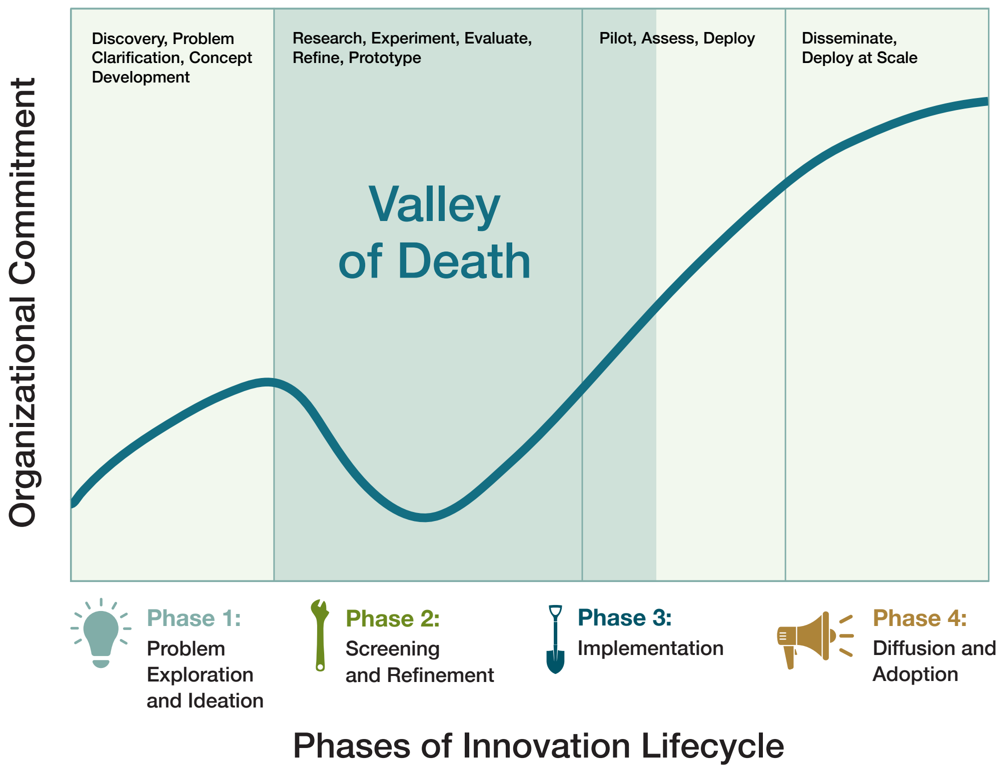
Innovation is the process of creating value by developing and implementing novel solutions to climate adaptation challenges.

Despite the growing impacts of climate change on both the natural world and human communities, most adaptation efforts are still largely based on conventional approaches and designed to achieve incremental change. This reliance on conventional approaches, however, contributes to a growing mismatch between the scope and magnitude of climate change and the level of adaptation response needed—what is sometimes referred to as the *adaptation gap*. There is an urgent need for innovation to close that gap and effectively meet emerging climate challenges. Indeed, if climate adaptation is about not limiting future options, innovation is about expanding those options. Novel solutions will be needed that reflect both *sustaining innovations*, leading to improvements in existing practices or business processes, as well as *breakthrough innovations* capable of achieving truly transformational adaptation outcomes.

Over the past decade the conservation community has made major progress in incorporating climate change into its work, including through the development and adoption of intentional adaptation planning approaches. This includes a recognition that as climatic changes drive widespread ecosystem transformations, there is a need to manage for change, not just for the persistence of current or historical conditions. Innovative adaptation will be needed across that entire continuum of change—including new approaches to resist or accommodate changes, as well as to direct the trajectories of climate-driven change.

The Innovation Lifecycle

Innovation depends on creativity, insight, and inspiration, as well as a willingness to experiment, test assumptions, and learn from failure. Just as climate adaptation can be thought of as a process not an endpoint, successful innovation typically results from an intentional and iterative process. The *innovation lifecycle* shown below offers a framework for conceptualizing and understanding the overall innovation process, and serves as a central organizing theme for this guide. Distinguishing among the various



The innovation lifecycle, depicting the four phases in the overall innovation process. The “valley of death” refers to where a gap in organizational commitment can impede transition from concept development to deployment (adapted from NASEM 2016).

phases of this lifecycle—from problem exploration and idea generation through to implementation and broader diffusion—helps identify opportunities to craft and develop novel ideas and reveal where barriers may exist that can impede their development and application. This includes passage across the so-called *valley of death,* where promising innovations are at particular risk of neglect or abandonment.

Although depicted as an orderly series of phases and steps, the innovation process is not strictly linear, but instead should be viewed as a set of overlapping stages encompassing iterative cycles of ideation, refinement, implementation, and assessment. Nonetheless, the lifecycle offers a means to explore barriers and opportunities for promoting innovation, as well as to consider where and how innovation intersects with and can help support climate adaptation planning processes, such as the climate-smart conservation cycle.

Overcoming Barriers to Innovation

Innovation by its very nature involves doing things differently, yet breaking out of comfortable routines, business-as-usual practices, and conventional ways of thinking can be daunting. An array of barriers to innovation exists in the natural resources sector, and the guide explores a variety of these barriers in four major categories: *institutional barriers,* such as risk aversion and unsupportive institutional culture; *social barriers,* like operating in silos and lack of diversity; *knowledge and learning barriers,* such as limited knowledge and resistance to new ideas; and *capacity barriers,* including a lack of time, resources, and human capacity. The purpose of identifying and exploring these barriers is not to dwell on how difficult it is to innovate, but rather to provide context for how to overcome these hurdles.

To that end, the guide highlights a dozen *enabling conditions* that can foster creativity and innovation and help overcome those barriers. These enabling conditions encompass four broad categories: *institutional culture; governance and decision-making; knowledge and learning;* and *organizational capacity.* Each enabling condition is explored from the perspective of how and why the condition is important to creating a conducive environment for innovation. The guide also offers a set of "diagnostic questions" for each enabling condition to help individuals and institutions work toward advancing cultures, processes, tools, and practices that are conducive to successfully develop and implement innovative adaptation.

Managing Risks

Concern about the risks of trying something new—including a fear of failure—is one of the most significant barriers to innovative thinking and action. Consequently, the ability to adequately assess and manage risk is central to the innovation process. Climate change poses new risks to species and ecosystems, but also presents new challenges for risk assessment and management, for instance due to the loss of predictive power from historical data. As a result, there is a need to consider the risks associated with any particular adaptation approach, including unintended or maladaptive outcomes, along with the growing climate risks posed by inaction or a continuation of business-as-usual practices. Conservation and management actions almost always entail some level of risk, and an openness to taking risks—within acceptable levels—is key to enabling innovative adaptation thinking and action.

Innovative Adaptation in Action

Innovation, like climate adaptation itself, is a complex subject, and this guide covers a wide range of topics from the perspectives of both theory and practice. To help connect these two, the guide profiles a set of case studies that illustrate how barriers and enabling conditions for innovation have influenced these real-world applications of climate adaptation. These case studies explore adaptation responses to marsh loss along the Chesapeake Bay, climate-adaptive forestry in the Northwoods boreal forests, Tribal-led habitat restoration in the Pacific Northwest, fire management in Tasmanian wildlands, and permafrost protection in the Alaskan Yukon.

Rising to the Innovation Imperative

Innovation is best supported by a dynamic interplay between imaginative and insightful individuals and supportive institutions that nurture and promote creativity and innovation. This interchange involves the adoption of an *innovation mindset* within individuals and the creation of an *innovation culture* within institutions. Innovation, at the individual and institutional level, must be more than a buzzword, slogan, or cliché. Promoting innovation entails a commitment to processes by which novel solutions are developed, tested, and applied, and that contribute value to achieving meaningful adaptation and biodiversity conservation outcomes. The box below distills key concepts from throughout this guide that can help promote creativity and innovation in the practice of climate adaptation.

Addressing the intertwined and accelerating climate and biodiversity crises demands greater ambition, creativity, and innovation in the practice of climate adaptation. It is our hope that by exploring the concepts, conditions, and techniques for fostering creativity and innovation, this guide will enable and inspire the biodiversity conservation and natural resource management community to dramatically scale up its ambitions and capacity to carry out innovative and effective climate adaptation.

Key Concepts for Promoting Innovation in Climate Adaptation

- **Examine assumptions.** Assumptions should be routinely and regularly questioned, whether they concern the nature of the problem, the array of available management options, or the desired conservation and adaptation outcomes.
- **Shift perspectives.** Innovative solutions often come from redefining a problem, examining it in an unconventional way, or applying new information and novel insights.
- **Look at the whole system.** Understanding, and often resetting or broadening the boundaries of a system or problem can yield novel insights and suggest new pathways and solutions.
- **Embrace diversity in all its dimensions.** Diversity of expertise, disciplines, stakeholders, communities, cultures, and knowledge systems can help redefine problems, clarify shared and contrasting values, and reveal new opportunities.
- **Be collaborative.** Partnerships and collaborations are key to bringing suitable and relevant capacity, perspective, and expertise into play to creatively solve challenging problems.
- **Learn from failure.** Having the freedom to fail is key to successful innovation, and failure should be viewed, and embraced, as an opportunity for continual and iterative learning.
- **Be experimental.** Experimentation, including testing, evaluation, and refinement, provides a systematic method for developing, implementing, and assessing novel solutions.
- **Put risks in perspective.** Don’t let a general aversion to risk derail promising innovations; risks of any particular adaptation action should be weighed against the consequences of inaction.
- **Share what gets learned.** The diffusion and adoption of innovative adaptations depends on sharing ideas, experiences, and data, for both successes and failures.

A novel approach to help save Hawai'i's endemic forest birds involves use of the bacteria Wolbachia *to reduce populations of disease-carrying mosquitoes in high-elevation forests. Photo: 'I'iwi* (Vestiaria coccinea) *feeding on 'ōhi'a lehua* (Metrosideros polymorpha) *flowers. Credit: Raymond Lara/USFWS.*

Chapter 1. Innovation in Climate Adaptation

Barely 20 years ago, the fingerprints of anthropogenic climate change on species and ecosystems began to be well substantiated and documented (Parmesan and Yohe 2003, Root et al. 2003). Since then, the pace, scope, and magnitude of climate impacts have been accelerating, with increasingly serious implications for people and nature. As a result, the contemporary practice of biodiversity conservation and natural resource management must take rapidly changing climatic conditions into account, and be designed to intentionally respond to and address those g rowing impacts.

Addressing the problem of climate change on natural and human systems has two major components: climate mitigation and climate adaptation. *Climate mitigation* refers to efforts to reduce levels of greenhouse gases in the atmosphere, which are the driving force behind warming and other global climatic changes. By contrast, *climate adaptation* refers to efforts to address and adjust to the effects of climatic changes, both those already being experienced and those projected to occur. Stabilizing and ultimately reducing atmospheric levels of carbon dioxide and other greenhouse gases will be essential for long-term planetary sustainability, and mitigation efforts receive the majority of climate-related attention and investments in the United States and globally. Despite this, atmospheric greenhouse gas levels continue to rise, with carbon dioxide levels exceeding 420 ppm in 2023 compared with 370 ppm in 2000 and 315 ppm in 1958 (NOAA 2023a). As these levels rise, along with their associated impacts, the need for adaptation becomes more acute and urgent.

Climate adaptation is finally receiving more recognition and investment, in part due to a growing number of climate-fueled disasters, as well as from increasing evidence of climate-driven transformations in ecological systems and human communities. Over the past decade there have been major advances in approaches to adaptation planning and implementation. This includes the development of robust adaptation principles and practices tailored to the needs of biodiversity conservation and natural resource managers. Adaptation planning approaches such as the "climate-smart conservation" planning framework (Stein et al. 2014), the resist-accept-direct framework (Lynch et al. 2021, Thompson et al. 2021, Schuurman et al. 2022), and the U.S. Forest Service adaptation workbook (Swanston et al. 2016) are being adopted and used by increasing numbers of resource managers in federal and state agencies as well as private sector organizations. Along with the uptake of these adaptation planning approaches has been a trend toward incorporating climate adaptation and resilience strategies in on-the-ground projects, and embedding adaptation criteria in federal and private funding opportunities.

Despite these advances, the adoption and application of climate adaptation across the conservation and natural resource management community continues to lag. Many natural resource professionals still are not consistently incorporating climate considerations into their work. There are many reasons for this, including a lack of understanding of how climate change is—or may be—affecting the resources of management interest, a lack of familiarity with the tools and approaches for adaptation planning, a lack of or unclear climate-related institutional policies or mandates (Hagerman 2016), and/or a belief that climate change is still a future threat that is disconnected from, and has less urgency than, existing or more near-term threats. Even when managers do incorporate climate considerations into their work, most adaptation strategies continue to be based on conventional practices (McLaughlin et al. 2022, Hansen et al. 2023). As a result, at present most adaptation plans and approaches tend to be incremental in nature, emphasizing a relatively limited and conventional suite of conservation approaches, and designed to continue meeting traditional conservation goals and objectives. Indeed, there is a growing mismatch between the scale and scope of climate-related impacts and the adaptation responses currently being carried out or in the pipeline, a situation known as the *adaptation gap* (UNEP 2022). To address this mismatch, there is a need for planners and managers to be more creative, innovative, and bold in the development and implementation of adaptation responses.

1.1. Innovation in the Service of Effective Adaptation

The purpose of this guide is to promote more creativity and innovation in climate adaptation to meet the growing challenge of conserving and managing natural systems in the face of rapid climate change. To be clear, our interest is *not* in promoting innovation for the sake of innovation. Rather, it is to help policymakers, researchers, and managers harness the power of innovation to carry out biodiversity and ecosystem adaptation more effectively.

"Innovate" derives from the Latin word *novus* (new), and novelty is at the heart of the concept. What, however, is the role of novelty in adaptation? To some, the very act of "adapting" suggests that the practices or approaches being deployed are or should be considered new or novel. In contrast, our view of adaptation suggests a more nuanced role for novelty.

A general definition for climate adaptation is "the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities" (IPCC 2022). In practice, however, most natural resource–oriented adaptation focuses on reducing climate-related risks and vulnerabilities. Accordingly, one of the core principles of climate-smart conservation (Box 1.1) centers on the concept of *intentionality*, meaning explicitly linking adaptation actions with specific climate impacts and risks. Under this principle, the determinant of whether an action can legitimately be viewed as "climate adaptation" has less to do with whether it is new, and more to do with whether there is a well-defined connection to reducing specific climate risks—or

Box 1.1. Key principles for climate-smart conservation (from Stein et al. 2014).

- Act with intentionality through linking actions to climate impacts
- Manage for change, not just persistence
- Reconsider goals, not just strategies
- Integrate adaptation into existing work

take advantage of climate-related opportunities. Accordingly, well-designed adaptation strategies and actions can involve the use of existing or conventional practices or approaches, or can employ novel practices and strategies. Thus, not all adaptation must be "innovative"—there will continue to be an important role for conventional practices in well-designed and intentional adaptation plans. Nonetheless, as the pace, scale, and scope of climate-related impacts grow, pushing species and ecosystems into truly uncharted territory, relying only on conventional, or "business as usual," conservation approaches will be a recipe for failure. Innovation and the development of novel responses to climate change and its impacts will increasingly be imperative for long-term conservation success, as discussed in Chapter 2.

1.2. What Does Innovative Adaptation Look Like?

Innovation is a much-admired trait, and ingenuity and inventiveness form an important part of our collective psyche. Pinning down what innovation is, and what innovative actions look like, can be surprisingly challenging, though. This guide explores innovation from various perspectives, including its attributes, drivers, and enabling conditions. Nonetheless, recognizing innovation remains somewhat subjective, calling to mind former Supreme Court Justice Potter Stewart's famous observation—on an entirely different topic—that "I know it when I see it."

Innovation can be considered to have three key attributes—novelty, value, and process—as explored in Chapter 4's deep dive into the theory and practice of innovation. Building on these concepts, we adopt the following definition of innovation from the perspective of biodiversity and ecosystem adaptation:

Innovation is the process of creating value by developing and implementing novel solutions to climate adaptation challenges.

Innovative adaptation encompassing those three attributes can derive from several pathways for generation, development, and deployment. First, innovations can result from the creation of truly *new* ideas or approaches. Second, they can reflect novel applications or the *transfer* of ideas or practices

Innovations can be truly novel ideas, can reflect the transfer of new approaches from one sector to another, or—as with these low-tech rock structures for stream restoration—can draw from or revive ancient or historical practices. Photo: Wolf Creek restoration, Gunnison Basin, Colorado. Credit: Betsy Neely/TNC.

first developed in other sectors, geographic regions, or communities of practice. Finally, innovation can involve a *revival* or renewal of traditional, historical, or ancestral approaches or practices.

One can also view innovation through the lens of climate vulnerability and its three constituent components of exposure, sensitivity, and adaptive capacity (Glick et al. 2011, Foden et al. 2019). Given that most adaptation in the biodiversity and ecosystem sector focuses on reducing climate-related vulnerabilities, adaptation strategies usually are designed to reduce exposure to climate-related stressors and impacts, reduce the sensitivity of the target resource to those impacts, or enhance the adaptive capacity of the resource (or some combination of the three). Below, we offer a few brief examples of innovation in conservation and adaptation, but also refer the reader to Chapter 8, which offers a more expansive set of case studies.

Putting beavers to work on behalf of salmon. Many adaptation efforts are targeted toward reducing exposure of organisms to the climatic changes or impacts themselves, for example, cooling water temperatures in salmon spawning streams. Conventional approaches to this problem might involve replanting riparian tree canopies to offer shade, or releasing cool bottom water from upstream dams. An innovative approach to reducing salmon exposure to warming water is to employ process-based restoration approaches, such as the reintroduction of beavers into watersheds from which they have been extirpated (Wheaton et al. 2019). Beavers are natural ecosystem engineers whose activities and dam building can improve wetland and riparian habitat and lead to reductions of stream water temperatures (Dittbrenner et al. 2022). The Tulalip Tribes of Western Washington have successfully deployed this restoration technique to enhance salmon habitat in the upper Skykomish River basin, drawing on both Indigenous knowledge and Western scientific understanding. This innovative project reimagined and transformed a perceived social and environmental problem ("nuisance" beavers) into a beneficial adaptation solution, and paved the way for the broader adoption of this technique by other Tribes and non-tribal entities (Section 8.3).

The Tulalip Tribes of Washington melded Indigenous knowledge and Western science to put "nuisance" beavers to work in restoring salmon habitat. Photo: Biologists releasing beavers in the upper Skykomish River basin. Credit: Northwest Treaty Tribes.

Deploying bacteria to save endangered Hawaiian birds. Reducing exposure to a climate-related risk is also at the heart of an innovative new initiative in Hawai'i intended to avoid the extinction of forest birds imperiled by disease-carrying invasive mosquitoes *(Culex quinquefasciatus)*. The introduction to Hawai'i of mosquito-borne avian malaria *(Plasmodium relictum)* has decimated populations of endemic birds, especially at lower elevations, and played a role in the extinction of many of these species (Samuel et al. 2015). Cool, high-elevation slopes inhospitable to mosquitoes have long served as a disease-free refuge for Hawaiian forest birds. As climate change leads to warmer air temperatures in Hawai'i, mosquitoes are expanding their range into these higher elevation forests, putting many of the remaining endemic forest bird species at imminent risk of extinction. The U.S. Department of the Interior, in collaboration with the State of Hawai'i, the Native Hawaiian Community, and other local and national partners, is launching an ambitious, landscape-scale effort to reduce mosquito populations responsible for infecting forest birds with avian malaria (DOI 2022). This initiative will rely on the naturally occurring bacteria *Wolbachia* to suppress mosquito reproduction and population size in forest bird habitats, using what is known as the "insect incompatibility technique" (IIT). Implementing *Wolbachia* IIT to stave off the extinction of Hawaiian birds is an approach that directly builds on the extensive development, testing, risk assessment, and application of this technique for disrupting disease vectors affecting human health (WMP 2023). This bold wildlife adaptation strategy, which is moving through its planning, consultation, and regulatory approval phases, therefore represents the transfer of a novel solution first developed for another use—in this instance, in the public health sector.

Driving pied flycatchers to recalibrate the timing of migrations. Moving species from one place to another, often referred to *as managed relocation* or *assisted migration,* is an innovative adaptation strategy for enabling species to keep pace with shifting climatic conditions (Box 3.1). Recent research on European pied flycatchers *(Ficedula hypoleuca)* offers an intriguing and novel example of how relocating individual birds can enhance a species' adaptive capacity in the face of shifting seasonality (Lamers et al. 2023). Pied flycatchers are migratory songbirds that overwinter in West Africa and breed in Europe. In the Netherlands, climate change is causing spring to arrive earlier, resulting in a phenological mismatch between the arrival of these migratory birds on their breeding grounds and the emergence of the caterpillars that are essential to feeding their nestlings. Researchers found that by driving pied flycatchers north from the Netherlands to Sweden, they were able to recalibrate the timing of the bird's migratory arrival relative to local conditions, resulting in improved breeding success. Indeed, within two years, the relocated Dutch birds were producing more than twice as many surviving offspring as their Swedish counterparts. The progeny of the Dutch birds exhibited inherited timing in their migrations, demonstrating the potential for directed dispersal as an evolutionary force in adaptations to climate change-related shifts in seasonality (Lamers et al. 2023).

Exploding decoys and green lasers to protect baby desert tortoises. Some of the most interesting and innovative conservation work currently underway focuses on the plight of the desert tortoise *(Gopherus agassizii)* in California. Desert tortoises, a federally listed threatened species, have been in decline for many years as a result of numerous factors, which now include climate change-associated increases in aridity, expansion of invasive species, and changes in fire regimes. Among the most serious threats, however, is the artificially high population of ravens *(Corvus corax)* in the region. Ravens are voracious predators of young and baby tortoises and are now responsible for seventy to ninety percent of tortoise mortality (Segura et al. 2020). Ravens were once uncommon in the California deserts but due to expansion of human activities—and the species' remarkable intellect and ability exploit

Creative approaches for protecting young desert tortoises include the use of aversion training to deter raven predation. Photo: Baby desert tortoise, Joshua Tree National Park, California. Credit: Daniel Elsbrock/NPS.

human development, including trash—they have increased by an estimated 1,000 percent in the last 35 years (NPS 2023). Tim Shields, a longtime tortoise researcher and conservationist, has been leading an effort focused on devising new approaches for reducing raven predation of tortoises. This includes novel spins on conventional approaches to predator control, such as the use of drones to oil raven eggs while in the nest, as a means of lowering population growth rates. His work on applying the principles of *aversion training* to ravens, however, reflects truly outside-the-box thinking. This includes the discovery that green lasers serve as powerful and lasting deterrents to ravens. Indeed, the work he and his collaborators at Hardshell Labs have carried out on laser repulsion of nuisance birds was recognized with a 2022 U.S. Fish and Wildlife Service Theodore Roosevelt Genius Prize (Section 4.5.1). Even more intriguing, this team has been developing realistic-looking baby tortoise decoys armed with explosive doses of pepper spray, designed to deliver aversive training to these highly intelligent birds. Reflecting on the search for creative new approaches to address the problem of raven predation on tortoises, Shields says, "I think there's a thing that runs in us which is the critic, the critic of our thoughts...And the little voice in me said 'That's absurd,' and I just turned to the little voice and I said, 'Shut up!'" (Izenberg and Marty 2023).

1.3. Structure of This Guide

This guide builds on and adds to the growing body of work designed to assist conservation practitioners and natural resource managers to employ intentional approaches to climate adaptation in their work, and is an extension of guidance for application of the "climate-smart conservation" framework for biodiversity and ecosystem adaptation (Box 1.1; Stein et al. 2013, 2014). As noted above, our emphasis here is on how to enhance the effectiveness of adaptation efforts by encouraging more creativity and innovation in how resource planners and managers think about conservation strategies and actions, as well as underlying conservation goals and objectives. Asking the "sufficiency" question—that is, how much adaptation is enough and what does that look like—continues to present a central dilemma for many natural resource practitioners.

Although biodiversity conservation and natural resource management are carried out in both the public and private sector (e.g., nonprofit organizations, corporations, and private landowners), in the United States federal and state agencies have an outsized role in the management of natural lands and waters. Public sector land and water managers often operate under additional constraints—political, legal, jurisdictional, economic, or cultural—that can affect their capacity to innovate. For this reason, the guide pays special attention to some of the barriers and opportunities that may apply to agency planners and managers, as well as lessons from the private sector with relevance to public land and resource managers. While this guide focuses on innovative adaptation in the biodiversity and natural resource sector, its general principles have relevance to other sectors, particularly where nature-based solutions are being considered in community adaptation plans and to protect the built environment.

The guide explores the issue of innovation in the context of biodiversity conservation and natural resource management, but draws extensively from the conceptual and practical applications of innovation in other sectors, particularly the business and technology sectors. The guide is structured to first offer general information about what innovation is and why innovation is important for climate adaptation in the natural resources sector. The guide then examines key barriers to the practice of innovation before offering a set of "enabling conditions" for overcoming those barriers.

The guide also builds on a conceptual framework for innovation development and implementation referred to as the *innovation lifecycle* (Figure 1.1 and Section 3.1). This framework allows us to deconstruct the process for innovation by distinguishing its various phases, from problem exploration and idea generation through to implementation and diffusion. Exploring the innovation lifecycle is also helpful in identifying where there are opportunities to promote innovation by natural resource planners and managers, and where barriers may exist that impede the development or application of novel ideas, including passage across the so-called *valley of death* (Markham 2002, NASEM 2016). Just as adaptation planning can be carried out as a stand-alone exercise or integrated into existing planning processes, the innovation lifecycle can support stand-alone efforts designed to craft novel solutions and innovations, or (and likely most often) elements of the cycle can support and be incorporated into broader participatory adaptation planning efforts. In both instances, the end result should be the identification of novel approaches that can effectively address biodiversity and ecosystem adaptation challenges.

This guide has been structured to explore the topic of innovation from both a conceptual and practical basis, starting with why more innovation is needed before discussing the conceptual basis for innovation and challenges and opportunities for incorporating innovation in adaptation practice and institutional culture. Below is a brief summary of each chapter's content:

Chapter 2. The Case for Innovation. Chapter 2 offers a review of the current state of adaptation and why more innovation is needed in the practice of adaptation for biodiversity and ecosystem conservation. The chapter also explores the concept of "sufficiency" in adaptation—in essence, how much is enough and what constitutes effective adaptation.

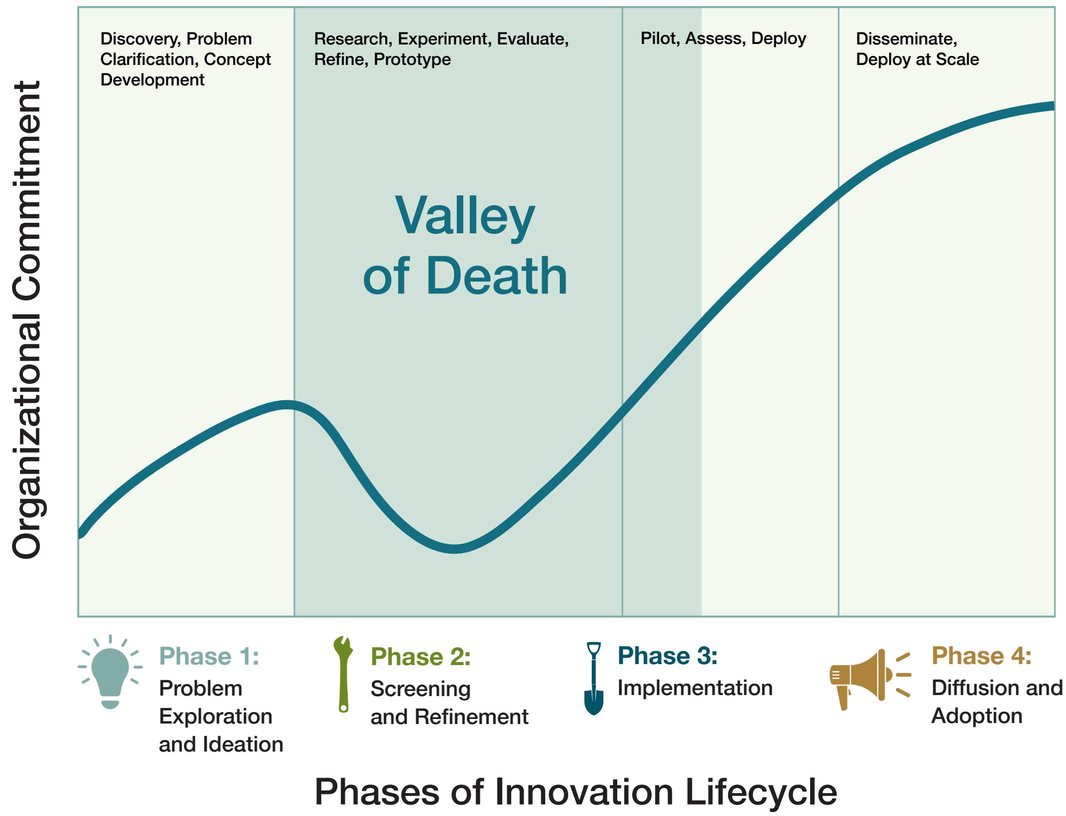


Figure 1.1. The innovation lifecycle, illustrating the four phases in the overall innovation process. The “valley of death” refers to where a gap in organizational commitment and investments can impede transition from concept development to deployment (adapted from NASEM 2016).

Chapter 3. Traversing the Innovation Lifecycle. Chapter 3 discusses the “innovation lifecycle” and its associated “valley of death.” The chapter also considers how the innovation lifecycle links to and can support adaptation planning processes such as the climate-smart conservation cycle.

Chapter 4. Exploring Innovation Theory and Practice. Chapter 4 offers a deeper exploration into the meaning of innovation and key concepts related to its generation and diffusion. This chapter also reviews various types of innovation, key drivers, and different techniques for generating ideas and for advancing innovative ideas and practices, including by productively learning from failure.

Chapter 5. Barriers to Innovation. Chapter 5 examines various barriers to the practice of innovation in the natural resources sector, including institutional barriers, social barriers, knowledge barriers, and organizational capacity barriers.

Chapter 6. Enabling Conditions for Innovation. Chapter 6 identifies a set of factors or “enabling conditions” for overcoming the barriers highlighted in Chapter 5, and which can foster creativity and innovation within an agency or organization. Enabling conditions address various aspects of institutional culture, governance and decision-making, knowledge and learning, as well as organizational capacity.

Chapter 7. Assessing and Managing Risks from Innovation. Chapter 7 delves into the crucial topic of assessing novel solutions and approaches for their risk of adverse outcomes, and explores options for managing risks. The chapter also considers how assessing and managing risk fits into the various phases of the innovation lifecycle.

Chapter 8. Innovation in Action: Case Studies. Chapter 8 highlights several real-world examples of innovative adaptation in the biodiversity and natural resource realm. These case studies illustrate how the barriers and enabling conditions described in this guide have influenced these applications of climate adaptation.

Chapter 9. Rising to the Innovation Imperative. Chapter 9 explores the dynamic interplay between adopting an "innovation mindset" and creating an "innovation culture," offers recommendations for embedding innovation in conservation policy and practice, and distills key concepts and lessons for policymakers, researchers, and resource managers to scale up their ambitions and capacity for carrying out innovative and effective climate adaptation.

1.4. How to Use the Guide

Innovation, like climate adaptation itself, is a complex subject, and this guide covers a wide range of topics from the perspectives of both theory and practical applications. Depending on the reader's interests and background, some chapters and sections of the guide may be more relevant than others. Although there is an intentional flow to the presentation of topics, it is not necessary to read the guide from beginning to end. Rather, users may find it valuable to explore those chapters and sections that most closely match their interests and needs.

A few sections of the guide, however, are foundational to understanding the general concepts and key messages for promoting innovation in the practice of climate adaptation. **Chapter 2** offers a high-level perspective on why innovation in adaptation is urgently needed to address the growing impacts of climate change on the natural world. **Chapter 3** provides an overview of the "innovation lifecycle" around which much of this guide is structured, and describes how innovation fits into and can enhance adaptation planning processes (Section 3.3). **Chapter 4** offers a review of various elements of innovation theory and practice, including specific approaches and techniques for innovation generation (**Section 4.5**). Chapters 5 and 6 explore the flip side of the same question—what barriers inhibit innovation in natural resource–focused adaptation, and how can those barriers best be overcome? While **Chapter 5** offers an in-depth examination of key barriers, readers may choose to focus instead on the factors and conditions presented in **Chapter 6** that help to promote creativity at the individual level and innovation at the organizational level. Those "enabling conditions" are summarized through a series of diagnostic questions found throughout that chapter and which are presented in a consolidated form in Appendix A. The case studies in **Chapter 8** can serve to connect the more theoretical concepts with real-world examples, while **Chapter 9** offers a distillation of lessons and concepts drawn from across the guide.

The material in this guide is relevant to readers who have different levels and types of responsibilities in a conservation and natural resource management context (Section 9.2). *Policymakers* and *funders*, for instance, might use this information to consider creating policies, funding programs, or other incentives aimed at spurring creativity and innovation, including through reducing institutional and regulatory barriers to innovative actions. This could include ensuring that costs, benefits, and risks of novel solutions are fairly evaluated against the climate risks and impacts that would be incurred by inaction or a continuation of status quo approaches. *Researchers* and *educators* should be interested in the techniques for generating novel insights and solutions, and for devising meaningful approaches (e.g., through experimentation, monitoring, modeling, or synthesis) for exploring the potential efficacy of those new ideas. Approaches for harnessing innovation should be relevant for training programs and academic curricula designed to prepare the next generation of conservationists and adaptation professionals. *Natural resource managers* and other *conservation practitioners* may be interested in how an innovation can be more fully incorporated into adaptation planning and resource management initiatives, including the design and implementation of adaptive management efforts. Field-level practitioners are often in the best position to observe emerging challenges as well as detect when conventional practices may be insufficient or failing and there is a need to innovate in the development of new approaches.

Climate-driven ecosystem transformations will increasingly require innovative adaptation approaches, whether managers choose to resist, accept, or direct the trajectory of change. Photo: Burning Joshua tree forest during the 2023 York Fire, Mojave National Preserve, California. Credit: Ty O'Neil/AP Photo.

Chapter 2. The Case for Innovation in Adaptation

Climate change poses problems that challenge the underlying assumptions and expectations upon which many conservation policies and practices are built (e.g., climate stationarity, natural range of variability, appropriateness of historical norms and targets). As a result, many conventional biodiversity conservation approaches and practices are likely to become increasingly anachronistic, obsolete, or even maladaptive. This points not only to a growing need to center climate adaptation in conservation policy and practice, but for these approaches to be bolder and more innovative if adaptation outcomes are to be commensurate with the scope of the climate challenges ahead.

Despite decades of warnings and calls for action to slow greenhouse gas emissions, carbon dioxide concentrations in the atmosphere have continued to rise, resulting in increasingly evident climatic changes that are affecting people and ecosystems around the globe. Indeed, during the summer of 2023 average global temperatures for the first time exceeded 1.5°C above pre-industrial levels for an extended period, and the year is currently on track to be the hottest on record (NOAA 2023b). Similarly, with 25 billion-dollar-plus climate and weather disasters in 2023 (through October), the United States has set a new record for such disasters (NOAA 2023c). Globally, climate impacts are being felt by virtually all sectors and in all regions, ranging from public health crises due to extreme heat and spreading disease, to agricultural failures, political destabilization, and large-scale human migrations driven by drought, flooding, and other extreme weather disasters (IPCC 2022).

The impacts of anthropogenic climate change on the natural world are also becoming increasingly evident, putting at risk many of the biodiversity conservation achievements of the past century (Staudinger et al. 2013, IPBES 2019). Species responses to changing climatic conditions vary widely, but include shifts in range to track suitable climates (Chen et al. 2011), decline in or extirpation of populations (Wiens 2016), and even species-level extinction events (Cahill et al. 2013). Species already rare or in decline from threats such as habitat loss and fragmentation, invasive species, and pollution are being further imperiled by the compounding and synergistic effects of climate change. Similarly, ecosystems are showing widespread effects of and responses to climatic changes, including shifts in composition, structure, and function often mediated through climate-amplified changes in disturbance regimes in concert with anthropogenic stressors such as habitat fragmentation and alteration of natural processes. Indeed, climate-driven ecosystem transformations are now becoming widespread (Thompson et al. 2020), often resulting in novel system configurations that lack historical analogs (Hobbs et al. 2009, 2018). Climate-driven transformation of ecosystems also has implications for the many cultural, material, and economic benefits that humans derive from natural systems. This includes a loss of protective benefits, such as flood risk reduction, that ecosystems provide to communities. As a result, the climate impacts on species and ecosystems can exacerbate climate risks and vulnerabilities to people, property, and livelihoods.

Natural resource managers and policymakers are now faced with a formidable task—stewarding ecosystems and biodiversity in a manner capable of sustaining desired ecological functions and preventing mass extinction in a rapidly changing climate. Given the accelerating pace and scale of climate change, and the still limited scope and effectiveness of adaptation efforts undertaken to date, there is a considerable "adaptation gap" (UNEP 2022). Addressing this gap will require innovative and transformational approaches to adaptation that greatly exceed most of the incremental efforts to date.

Addressing the growing impacts of climate change on natural systems will require the ability to consider solutions and processes for which there may not be a strong precedent in existing practice. Unfortunately, the adaptation actions currently prevalent in biodiversity and natural resource management, do not appear to match the magnitude of this challenge. Furthermore, there is an inadequate range of adaptation actions currently available or in use that benefit both vulnerable biodiversity and vulnerable human communities (including Indigenous communities, communities of color, and low-income communities). All of this suggests that simply mainstreaming current conservation and resource management approaches to adaptation will be insufficient to avoid irreversible harms and unable to sustain desired biological, ecological, and social outcomes.

Early innovations in climate adaptation focused on raising awareness of the need for adaptation, and showing that pathways exist for adjusting to and ameliorating some of the adverse impacts of climate change (Hansen et al. 2003). Such early efforts were often hindered by a perception in the broader climate action community that merely acknowledging the role of adaptation would undermine the urgency of climate mitigation actions (Pielke et al. 2007). As the impacts of climate change have become better understood, and are now being acutely felt, that early conflict has given way to a realization that adaptation is an essential complement to climate mitigation in addressing the climate crisis. Nonetheless, it is also clear that there are limits to adaptation and that without substantive action on reducing atmospheric carbon concentrations, options for avoiding intolerable climate thresholds will be severely restricted (Dow et al. 2013, Stein et al. 2013).

As the manifestations and impacts of climate change continue to become more and more tangible across regions and society, leading to greater interest in both adaptation and mitigation, most policies and actions are still generated reactively, often in response to disasters. Proactively addressing climate risks continues to be a challenge, as is identifying up front what successful adaptation would look like if such efforts were undertaken (Moser and Boykoff 2013). Even when adaptation plans and actions are implemented, they generally reflect a repurposing or reuse of existing strategies without an explicit, holistic evaluation of the range of potential impacts (both climatic and interactive non-climatic). This is no doubt in part due to the relative recency of the discipline of climate adaptation. Conservation and natural resource management have long histories and traditions, whereas climate adaptation as a field has existed for only a few decades. It is not surprising, then, that our collective thinking about adaptation to date has been constrained, particularly since there is not yet a clear vision for what constitutes sufficient and effective adaptation outcomes over the long term (Section 2.2).

2.1. A Reliance on Conventional Approaches

Despite the accelerating impacts of climate change on both the natural world and human communities, most climate adaptation efforts are still largely based on conventional approaches. This reliance—or overreliance —on conventional approaches contributes to the growing mismatch between the scale and scope of climate-related impacts and the level of adaptation response needed. Addressing this "adaptation gap" will require far more creativity and innovation in adaptation planning and practice than is currently the case. Indeed, Arteaga et al. (2023) have highlighted an "imagination gap" in the theory and practice of climate adaptation that they describe as a lack of vision of "where and what's needed that hasn't been seen before within our current systems."

Attention to climate adaptation in the conservation and natural resource management community has grown considerably over the past two decades, having received a significant boost in the late 2000s when legislation before the U.S. Congress included the prospect of significant adaptation funding for natural resource agencies (NFWPCAP 2012).[1] Over that time period, there has been considerable progress in the development of conceptual frameworks and practical guidance for incorporating adaptation into biodiversity and natural resource management (e.g., Stein et al. 2014, Swanston et al. 2016, AFWA 2022) and for testing these concepts in on-the-ground projects (Cross et al. 2018). Nonetheless, application of adaptation within the natural resource management community continues to be constrained and often narrowly focused. Much of the work described as adaptation relies on the repurposing of conventional management approaches and continues to focus on achieving existing—and often climate-compromised—conservation goals. Additionally, most adaptation actions focus on addressing single climate impacts (e.g., living shorelines for sea-level rise, establishment of shade for heat), or single resources (e.g., individual endangered species). Another constraint in the conservation and natural resource sector centers on concerns about uncertainties and risks associated with novel interventions, such as occurred in the case of managed relocation strategies (Box 3.1).

Evidence for the reliance on conventional approaches can be found in the scientific literature on adaptation. Heller and Zavaleta (2009) and later McLaughlin et al. (2022) systematically reviewed the peer-reviewed literature to determine what strategies and actions have been most frequently recommended to address the impacts of climate change on species and ecosystems. They found that the most frequently recommended adaptation actions have remained remarkably consistent over the last three decades, and that the literature continues to recommend mainly "conventional, longstanding conservation approaches" (McLaughlin et al. 2022). For example, "increase connectivity" and "protect or restore ecosystem structure or function" remain the top two recommended actions, followed by other generic and traditional approaches such as "manage at

[1] Federal climate legislation that in 2009 passed the U.S. House of Representatives (H.R. 2454, 111th Congress) but not the Senate would have created a Natural Resources Climate Change Adaptation Fund, funded through a cap-and-trade program on greenhouse gas emissions, and intended to "carry out natural resources adaptation activities in accordance with State natural resources adaptation plans."

larger scales," "conduct monitoring," and "mitigate non-climate threats." Other reviews of adaptation recommendations for biodiversity conservation (Prober et al. 2019), wildlife management (LeDee et al. 2020), and forest management (Hagerman and Pelai 2018) reveal similar results, with "low-regrets, low-risk options" constituting the most commonly cited strategies. While a focus on existing strategies may simplify and make adaptation more approachable for managers, reliance on these familiar approaches will almost certainly constrain the capacity to keep pace with rapid changes and achieve effective adaptation outcomes. The importance of going beyond such conventional, low-risk approaches was highlighted by McLaughlin et al. (2022), who note that "the magnitude of the accelerating climate crisis requires aggressive development and testing of innovations in biodiversity conservation."

One effort to improve the accessibility of adaptation approaches for planners and managers has been the advent of "adaptation menus," offering consolidated lists of possible adaptation tactics for a given community of practitioners (e.g., Ontl et al. 2020, Janowiak et al. 2021, Handler et al. 2022). These menus can be a useful tool for demystifying adaptation and, when used appropriately, can help managers identify strategies or tactics potentially relevant to addressing climate risks in their particular circumstance. Adaptation menus can also serve as a prompt for going beyond what is listed and thinking creatively about possible new solutions that could address the climate-related problem at hand. However, managers might also assume that because a tactic is listed on an adaptation menu, its application therefore constitutes a "climate adaptation" regardless of its connection (or lack thereof) to the climate-related vulnerabilities of the resources of concern.[2] By emphasizing existing and mostly conventional management approaches, an overreliance on pre-populated action menus could inadvertently constrain the development and implementation of innovative new adaptation approaches.

Box 2.1. Relying on what you have is not inherently bad.

Innovation need not be limited by the resources and approaches you have on hand. In fact, those limitations can be a stimulus for creativity. Consider, for example, the contents of your refrigerator. You can choose to eat an individual food item, just as it was put into the refrigerator—a stalk of broccoli, a piece of cheese, a stick of butter, a glass of wine. Or you could combine those items to create a more satisfying meal. This recombination could follow an existing and time-tested recipe or could be based on your own imagination (i.e., innovation) to create a satisfying and flavorful meal. You might also find that you lack some crucial ingredient in your recipe of choice and must improvise (i.e., innovate) in finding a substitute from among your available food stocks. Relying on conventional recipes or ingredients, whether in cooking or adaptation, may continue to meet your needs, while in other instances "changing it up" and exploring new options may be necessary to achieve your desired result. There are many paths to expanding our approaches, and we will need them all to meet the scale of the problem we face.

2.2. Is it Working? Evaluating Adaptation Effectiveness

Successfully adapting to climate change depends on an understanding of what success means, and this applies to novel or innovative adaptation approaches as well as more conventional methods. To date there is no consensus on how to define success in adaptation, and challenges remain in measuring the efficacy of individual actions as well as the sufficiency of collective adaptation efforts. On a global scale, the most recent UNEP (2022) "adaptation gap" report clearly states the problem in its title: *Too Little, Too Slow.* Part of the challenge of defining successful adaptation,

[2] As noted in Section 1.1, for any particular action, whether conventional or novel, to be considered climate adaptive, there should be a well-defined connection to reducing specific climate risks—or taking advantage of climate-related opportunities—a concept referred to as *intentionality* (Stein et al. 2014).

however, is that effectiveness must be viewed in relative rather than absolute terms; for instance, the extent to which reductions in climate risk result in improved human well-being or ecological outcomes relative to a "no-adaptation" baseline. In other words, adaptation may be "effective" even if only to slow the pace of species declines or ecosystem transformations. Indeed, the adaptation gap report offers the sobering caution that even effective adaptation options implemented at scale cannot fully prevent all climate-related losses (UNEP 2022).

Documenting the effectiveness of adaptation actions has been challenging in the biodiversity and ecosystem realm, and to date there is a shortage of evidence that the approaches being used are delivering successful adaptation. Indeed, many adaptation actions are assumed to be effective based on assumptions (and faith), rather than evidence (Hoffman and Hansen 2022). Hansen et al. (2023) surveyed the literature to find examples of where the "most recommended" adaptation approaches (as identified in Heller and Zavaleta [2009] and McLaughlin et al. [2022]) conferred adaptation advantage. Only 13 studies were identified that even tested the effectiveness of proposed adaptation actions (Hansen et al. 2023). Similarly, Bowgen et al. (2022) located just 77 studies globally that quantified the response of individual species' populations to climate-related management interventions, finding that actions were regarded as beneficial in just thirty percent of reported cases. Evidence is also lacking to know if the processes (e.g., guidance, capacity building, adaptation planning processes) in use to foster adaptation action are resulting in tangible, climate-smart management improvements.

Many existing actions already are being challenged by the current level and scope of climate-related impacts. From marine protected areas where corals bleach, to old-growth forests burning in unnaturally severe wildfires, to habitat restoration that is mismatched to changing conditions, conventional approaches may be applied without a clear understanding of the broader context underlying climate drivers and interactions. When unmodified to address that context and its intersections, they are unlikely to meet both current and future conservation needs. For example, riverine restoration efforts based on historical water levels and river flows might be billed as adaptation efforts because they "address water management" or are described as "enhancing resilience"; without taking into account projections of future precipitation and flooding patterns, however, such a project not only may fail to achieve its intended ecological outcomes, but may actually result in further habitat damage or loss.

2.3. Is It Enough? "Sufficiency" in Adaptation

Apart from understanding the effectiveness of individual adaptation actions, it is important to consider whether collectively these actions will be sufficient to achieve desired adaptation outcomes, including over the long term. Without an understanding of how much and what level of adaptation is necessary and sufficient, it can be difficult to distinguish between the adequacy of existing adaptation efforts and the need for more innovative approaches.

The "sufficiency" question in adaptation is fraught, however, requiring as it does the examination of often diverging societal values and goals for conservation and resource management, and the tension between the aspirational and the feasible. Traditionally, biodiversity conservation goals have focused on maintaining current ecological conditions or restoration to a historical (i.e., "more natural") state. Indeed, over the past few decades natural resource managers have adopted the concept of "historical range of variability" (HRV) or "natural range of variability" in recognition of the dynamic and fluctuating nature of natural systems and ecological processes (Landres et al. 1999). In the face of continuous and directional climatic changes, which are pushing many systems beyond their HRV, a return to historical conditions is increasingly implausible (Jackson 2012). Consequently, conservation and natural resource management goals will need to be future oriented, with desired outcomes often deviating (in minor or major ways) from historical benchmarks. Indeed, two of the key principles of climate-smart conservation (Box 1.1.) are to "reconsider goals, not just strategies" and "manage for change, not just persistence" (Stein et al. 2014). Being open and transparent about how conservation (and other societal) goals will need to evolve to become more climate-adaptive underlies efforts to characterize what constitutes sufficiency in adaptation.

The concept of sufficiency in adaptation can also be explored from several perspectives. For instance, will adaptation actions carried out locally add up to achieving sufficiency over larger landscapes and regions? Similarly, will actions designed to be effective in the near term be sufficient to achieve adaptation outcomes over the long term? Below, we explore the question of sufficiency with respect to spatial scale, temporal scale, equity, and magnitude of impacts.

2.3.1. Spatial Scale Sufficiency

To paraphrase a recent Oscar-winning film, climate change is happening to everything, everywhere, all at once. Although climate change is a global phenomenon, it is often said that all adaptation is local. To be effective, however, adaptations should be planned and implemented in the context of the broader landscape, seascape, and region. Not only does climate change interact with other stressors, but its impacts propagate and interact across and among ecosystems, even ecosystems that may not share boundaries. These compounding changes mean that limiting planning and actions to isolated parcels of land, water, or sea will not be effective or durable over the longer term. For example, the traditional approach of establishing protected areas, no matter how large, cannot alone safeguard these places from a changing climate given the pervasiveness of the climate threat (Bruno et al. 2018, Elsen et al. 2020).

Questions to consider regarding spatial scale sufficiency include:

- Are spatially confined approaches sufficiently coordinated among adjacent managers to yield landscape-scale effectiveness?
- What are the appropriate spatial scales for adaptation actions to ensure effective outcomes?
- Do species-specific approaches add up to broad effectiveness for entire ecological systems?

2.3.2. Temporal Scale Sufficiency

Adaptation actions are not just for the present, they are for the future. Many management actions are focused on immediate or near-term threats, but effective adaptation requires consideration of longer-term trajectories, both of climatic conditions and of ecological and human responses. Of particular importance is ensuring that near-term responses align with and do not compromise longer-term adaptation needs and requirements. Achieving temporal scale sufficiency will require consideration of how multiple, plausible climatic and ecological futures may play out, and adoption of adaptation strategies and actions likely to be robust (i.e., effective) across those multiple possible futures.

Questions to consider regarding temporal scale sufficiency include:

- Are tools that work for the next few decades sufficient to sustain adaptation beyond that, or are they vulnerable to failure as projected climatic changes advance beyond near- or midterm thresholds?
- Are any current or near-term management interventions likely to compromise potential adaptation responses needed in the longer term?
- What are the decision points at which resource managers need to consider changing to a different adaptation approach?

2.3.3. Equity Sufficiency

People are an integral part of the natural world, and biodiversity conservation typically involves working with and managing the relationship between natural ecosystems and human needs and livelihoods. Historically, conservation efforts have fallen short in adequately addressing the needs and aspirations of vulnerable and underserved populations, and have in many instances caused or exacerbated harms to local and Indigenous communities (West et al. 2006). Additionally, climate adaptation typically has accrued more benefits for dominant cultures and wealthier communities, leaving Tribal and Indigenous communities, communities of color, and low-wealth communities in the margins (Pelling and Garschagen

2019). The pressures that climate change is placing on both human populations and natural ecosystems will also likely magnify conflicts between humans and wildlife. Achieving sufficiency in adaptation will require a more inclusive and diverse set of participants in adaptation planning processes to ensure that benefits and risks are shared more equitably, and that maladaptive interventions do not impinge on already vulnerable and underserved populations.

Questions to consider regarding equity sufficiency include:

- Do adaptation goals and approaches consider equity for marginalized communities and across generations?
- Are adaptation goals and approaches sufficiently informed by Tribal and Indigenous communities, communities of color, and their leadership?
- Are adaptation goals and approaches considered holistically to ensure they are not maladaptive and pose increased risks to other communities, rights-holders, stakeholders, or sectors?

2.3.4. Magnitude of Impacts Sufficiency

The implications of climate change are large and vary by region. With the amount of carbon that has been emitted into the atmosphere and current greenhouse gas trajectories, the Earth already is committed to significant increases in temperature and sea level, as well as precipitation changes (Solomon et al. 2009). Moreover, since the modern science of climate change projections began, there have been few or no cases of projections decreasing in magnitude (becoming less different than today). Although climate models have predicted warming trends fairly accurately (Hausfather et al. 2020), the pace and severity of associated climate impacts appear to be outpacing expectations (IPCC 2022). Significant climate change impacts also interact with and exacerbate many of the non-climate stressors that many of our existing conservation approaches were initially designed to address (e.g., habitat loss and fragmentation, invasive species, pollution, overharvest) (Staudt et al. 2013). Furthermore, climatic changes are taking the world into a no-analog future, with combinations of climate variables with no historical precedent creating new uncertainties in forecasting ecological responses (Williams and Jackson 2007, Williams et al. 2007, Hobbs et al. 2009). As a result, changing climatic conditions both complicates existing problems, making them harder for current approaches to address, and creates an array of new, more complicated challenges that can compromise the effectiveness of conventional approaches and make it difficult or impossible to achieve existing goals and objectives.

Questions to consider regarding sufficiency relative to magnitude of impacts include:

- Do adaptation planning efforts consider the full range of plausible climate change effects based on the most current array of projections?
- Are interactions between climate change and other threats, now and into the future, considered in adaptation planning?
- Will the actions be able to deliver their intended benefits given on-going and often accelerating climatic changes and their interaction with other stressors?

2.3.5. Achieving Sufficiency in Adaptation

Achieving sufficiency in adaptation will depend on what conservation and other societal values are reflected in a collective vision of the future, and what adaptation outcomes would contribute to realizing that vision. Given the necessary magnitude, scale, and equity of climate change responses, the existing suite of approaches almost certainly will be insufficient to achieve durable conservation outcomes as climatic conditions continue to change and interact with other stressors. Rather, achieving sufficient and effective adaptation will require innovation in practice and perspective. This includes moving toward future-oriented conservation goals, planning for multiple plausible futures, and engaging diverse perspectives (especially those historically underrepresented and marginalized). Achieving sufficiency in adaptation will also require a shift from incremental adaptation actions to more transformative adaptation, addressing the roots and conditions of vulnerability rather than its symptoms (Shi and Moser 2021). Furthermore, over the long-term, successful adaptation will be dependent on meaningful climate mitigation. Each failure to meet an emissions reduction target means more adaptation is necessary and amplifies the sufficiency challenge. In addition, each newly identified climate impact, or increases in projected magnitude of a known impact, means that more adaptation will be necessary. Addressing new and growing climate impacts will almost certainly require innovative new approaches. In the absence of novel and effective solutions, the limits to adaptation may be reached sooner rather than later (Dow et al. 2013).

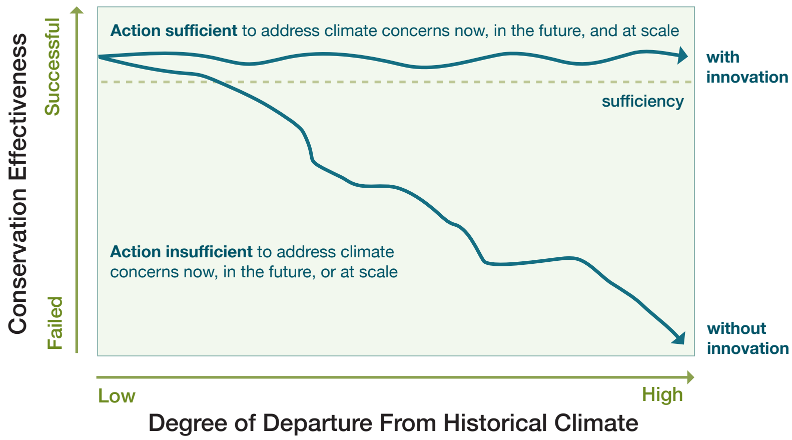


Figure 2.1. Conceptual role of innovation in addressing the sufficiency of adaptation actions.

Box 2.2. Exploring sufficiency in coral reef adaptation.

Increasing global ocean temperatures have resulted in coral bleaching in tropical oceans around the world. In the Florida Keys, where several coral species are already listed as threatened under the U.S. Endangered Species Act due to climate change (NOAA 2014), there has been extensive work to assess the vulnerability of coral reef ecosystems and to develop associated adaptation plans (Florida Reef Resilience Program 2010, Maynard et al. 2017), similar to the work undertaken for the Great Barrier Reef in Australia (Johnson and Marshall 2007, Great Barrier Reef Marine Park Authority 2012). Much coral conservation work in the face of climate change initially focused on conventional approaches, such as expanding protected areas, identifying and protecting areas less susceptible to bleaching, supporting connectivity, and protecting key species (e.g., grazers, predators, mangroves) (Marshall et al. 2006). As conditions have become more dire with coral mortality from disease and bleaching (including from effects of the unprecedented Florida ocean heat wave of summer 2023), the range of management options has expanded to include less conventional and more innovative approaches, such as targeted management and restoration of coral and zooxanthellae genetic diversity, physical manipulations (e.g., shading, mixing, deeper water restoration nurseries), establishment of ***ex situ*** gene banks, and use of genomic analysis to identify resilient restoration brood stock (Mydlarz and Muller 2023, NOAA 2023d). Some of these options may lead to a reexamination of the traditional goals of both marine protected areas and endangered species listings, which is to maintain and recover the species ***in situ***. As ecosystem transformations in some reef systems become inevitable and possibly irreversible, continuously changing climatic conditions may force managers to modify expectations of adaptation success and sufficiency.

Experimental shading of elkhorn coral (Acropora palmata)*, a climate-threatened species. This coral colony bleached during the intense ocean heat wave of summer 2023. Photo: Dry Tortugas National Park, Florida. Credit: Ilsa Kuffner/USGS.*

2.4. Innovating Across the Continuum of Change

Over the past two decades one of the most important innovations in the development of adaptation for biodiversity conservation has been a growing recognition that ecological transitions at some levels are inevitable, and managers increasingly will need to manage with, not just against, these trajectories of change. This concept first gained widespread attention through the work of Millar et al. (2007), who highlighted a continuum of management options they referred to as *resistance* (forestall impacts and protect highly valued resources), resilience (improve the capacity of ecosystems to return to desired conditions after disturbance), and *response* (facilitate transition of ecosystems from current to new conditions). The last of these, actually facilitating ecosystem transitions, represented a remarkable, and at the time controversial, advance in adaptation thinking. This concept has served as the basis of the core climate-smart conservation principle of "manage for change, not just persistence" and been built on and refined as the resistance-resilience-transformation framework (Peterson St-Laurent et al. 2021).

Yet another major advance has occurred in recent years with work to operationalize the principle of managing for change, resulting in development of the resist-accept-direct (RAD) framework (Schuurman et al. 2020, 2022; Thompson et al. 2020; Lynch et al. 2021). The RAD framework is designed to help managers understand the range of options and implications for addressing ecological transformations resulting from a changing climate or other directional changes. As described by Lynch et al. (2021), the triad of approaches can be characterized as:

- **Resist—**resist ecosystem transformations; management actions focus on maintaining current or historical ecosystem structure and function (services).
- **Accept—**accept ecosystem transformations; managers yield to ongoing transformations (i.e., by not intervening), accepting ecosystem structure and function that emerge from the transformation.
- **Direct—**direct ecosystem transformation toward a specific alternative outcome; managers accept that change is inevitable but intervene to steer the transformation toward an ecosystem state with particular structure and function.

By offering a framework for considering the full range of management options for these trajectories of change, RAD can instigate difficult conversations and decisions about what may and may not be feasible outcomes of management efforts. Importantly, these options are not mutually exclusive, and more than one may be deployed in the same place for different components of biodiversity (i.e., resisting changes to ecosystem structure but facilitating shifts in species composition). Furthermore, each option represents trade-offs among management goals, societal values, and available resources, and choosing an appropriate approach is informed by a number of factors, ranging from the pace and magnitude of projected changes, capacity of the resource to cope with or adapt to the changes, availability of suitable management techniques, and the feasibility of applying those approaches at the relevant scale.

Innovation is needed across the entire RAD spectrum, from resistance to transformation. The need for innovation may appear most obvious for developing interventions capable of facilitating or directing the trajectory of ecosystem shifts to achieve more desirable ecological outcomes than would otherwise be the case. There is also, however, a need for more innovation in resistance approaches, including where novel and unprecedented techniques may be needed to resist changes in order to protect irreplaceable or high-value resources.

2.5. New Challenges, New Opportunities

Climate change is generally seen as a new challenge in conservation, existing on top of the many and varied existing (or old) challenges that have not gone away. As such, there are several ways to think about applying conservation approaches to address both existing and emerging challenges (Figure 2.2).

Historically, natural resource managers have operated in the lower left quadrant (existing challenges, existing approaches), using a set of tools that were developed over time to address traditional conservation challenges. Although these tools may now be regarded as conventional, at some point in the past they may have been new and innovative but have since become widely adopted and mainstream (e.g., ecosystem-based management). In essence, they have successfully traversed the innovation lifecycle, discussed in Chapter 3.

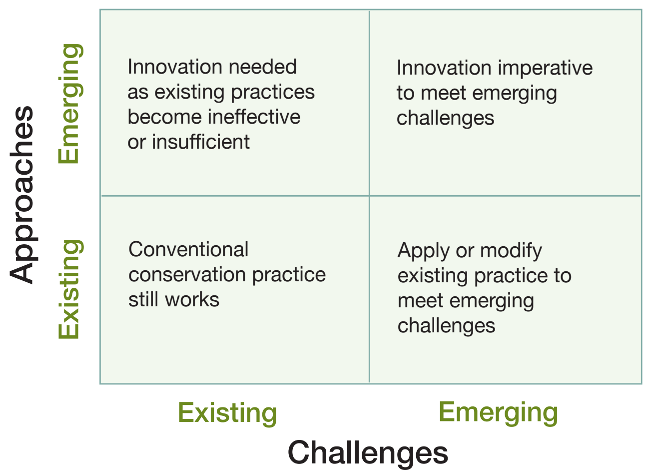


Figure 2.2. Adaptation action frames illustrating the relationships among existing and emerging conservation challenges and approaches.

The upper left quadrant represents where there are opportunities to innovate in the creation of new approaches to solve existing challenges. This could be out of necessity, such as where existing approaches are no longer effective, resources to undertake existing approaches are unavailable, or existing approaches are no longer socially or politically acceptable. This is also where emerging techniques or technologies might be borrowed from other sectors or communities of practice to address existing challenges.

The lower right quadrant, where new challenges are addressed through applying or modifying existing approaches, reflects the space in which most current adaptation efforts in the natural resource management community reside. Additionally, existing approaches may often be applied to emerging challenges out of reflex, regardless of their efficacy. Managers are no exception to the natural tendency to reach into the existing toolbox before considering whether a new tool of a different sort is needed. That said, there can also be innovation in finding creative reuses for conventional approaches and/or supporting long-standing or ancient practices.

Finally, the upper right quadrant (emerging challenges, emerging approaches) represents a space where innovation is an imperative, where new approaches can be designed to address evolving and entirely new challenges, including in light of new or updated conservation goals. This is where the least adaptation innovation has occurred to date and likely where there is the greatest opportunity to achieve the transformational change that climate change requires to achieve sufficient durable long-term conservation outcomes—however those come to be defined.

The apprehension to move into the upper left quadrant (emerging approaches to existing challenges) follows the pattern seen in the uptake of types of actions along the resistance-resilience-transformation continuum (Peterson St-Laurent et al. 2021). The majority of adaptation strategies currently applied fall into the “resistance” category, with an intent to sustain the persistence of current conditions. This is not surprising since these traditional approaches were designed to maintain existing or historical conditions (habitat type, species composition, ecosystem services) in a set location for the foreseeable future, often despite what climate projections indicate will be feasible. A growing number of adaptation strategies and actions are focused on the “resilience” category, particularly when resilience is defined from the perspective of facilitating rebound and recovery from climate impacts and other disturbances. It is notable, however, that most resilience actions are, at their root, focused on maintaining the persistence of current conditions. In contrast, there are as yet relatively few actions being undertaken in the “transformation” category. As noted previously, however, innovation is needed across the entire continuum of change, from resistance and resilience to transformation. Or in the context of the RAD framework (Lynch et al. 2021, Schuurman et al. 2022), innovation is needed in the design and execution of strategies across all three responses to trajectories of change: resist, accept, and direct.

2.5.1. Innovation Needed in Policy as Well as Practice

Natural resource management and climate adaptation do not exist in a vacuum. Rather, they operate in the context of laws, regulations, and other policies that govern decision-making, dictate resource limits and use constraints, and hold decision-makers accountable for the outcomes of their management choices. As explored further in Section 5.1.4, restrictive regulations and policies can be a significant barrier to carrying out forward-looking and climate-informed management and can serve as a deterrent to the development and adoption of innovations. Accordingly, just as there is a need for innovation in conservation practice, innovations in policy are needed—at international, national, state, and local levels—to address emerging conservation and natural resource management needs.

Regulations, policies, and even laws can and do evolve, and there are many examples of policy innovations successfully addressing serious environmental issues. As an example, in the late 20th century freshwater systems in the northeastern United States were becoming increasingly acidic due to the deposition of acid rain, causing major declines in aquatic organisms and disruption of aquatic systems. The adoption of an innovative cap-and-trade policy in the 1990 reauthorization of the Clean Air Act was hugely successful in reducing emissions of sulfur dioxide and nitrogen oxides from the power sector, which were the underlying cause of acid rain.[3]

Most legal and regulatory frameworks were developed under an assumption of climatic stationarity and are not well suited to providing the flexibility needed for managing resources under shifting climatic conditions. Indeed, even apart from the added challenges of climate change, many existing policies and regulations are not well equipped to support truly adaptive approaches to management and innovation (Ruhl 2005). Numerous examples exist of policies that can constrain innovation and climate-adaptive management responses. The Endangered Species Act (ESA), the nation's primary law for protecting plant and animal species from extinction, poses a number of constraints on forward-looking, climate-informed management. Changing climatic conditions raise many issues in ESA implementation regarding listing and delisting decisions and species recovery efforts, including through designation of critical habitat (Wentz 2022). For example, the act requires designation of critical habitat—geographic areas vital to the survival of a species at the time of listing—but many species are shifting ranges in response to changing climatic conditions (Hiers et al. 2016, Comacho and McLachlan 2021). Fortunately, there are opportunities even within the confines of a well-established legal framework like the ESA to develop innovative policy approaches for adapting to climate change. For instance, in 2023 the U.S. Fish and Wildlife Service updated regulations regarding "experimental populations" that explicitly allows for the translocation of listed species outside their historical range as a means, among other things, of tracking shifts in suitable climatic conditions (USFWS 2023).

More broadly, there are a variety of efforts underway at state and national levels to adopt policies and regulations that enable and support, rather than constrain, climate adaptation. For example, the U.S. government released a first-ever National Climate Resilience Framework that lays out a pathway for embedding climate adaptation and resilience considerations into a wide array of federal activities and policies (CEQ 2023). That framework highlights the importance of innovation by noting the "tremendous opportunity to further harness U.S. innovation capacity towards climate resilience." Individual federal agencies are also looking comprehensively at their policies and regulations through a climate lens. The Department of the Interior has recently issued a set of new departmental policies to emphasize that consideration of climate change is the default for planning and decision-making to support adaptation and resilience (DOI 2023). These new policies are also designed to encourage the use of adaptive management approaches, which are so critical to climate-adaptive management,

[3] While many economists consider that a comparable cap-and-trade program would be the one of the most efficient and cost-effective means of rapidly reducing carbon dioxide emissions, this uniquely American policy innovation has become politically toxic among many U.S. lawmakers.

and create opportunities for decision-makers to use managed ecological transformation approaches as well as nature-based solutions to reduce climate risks.

More innovation—and attention—is also needed in international policy for biodiversity and ecosystem adaptation. To the degree that adaptation for natural systems is addressed in most international conventions, it typically is through the lens of how ecosystems can reduce climate risks to people and livelihoods, rather than how to address climate risks to species and ecosystems themselves. Under the Convention on Biological Diversity, for example, the risks climate change poses to species and ecosystems are addressed under Target 8 of the recently adopted Kunming-Montreal Global Biodiversity Framework. That target acknowledges the need to increase resilience of biodiversity to climate change, but emphasizes the use of "nature-based solutions and/or ecosystem-based approaches," terms that while referencing natural systems, are actually focused on how nature and natural systems can offer protective benefits to people (Colls et al. 2009, Cohen-Shacham et al. 2016).[4] Reference to climate adaptation is conspicuously absent from other key Kunming-Montreal biodiversity targets, including those setting thirty percent spatial targets for protected areas (Target 3) and ecosystem restoration (Target 2).

Similarly, the Global Goal on Adaptation, established under the United Nations 2015 Paris climate agreement, has a primary emphasis on enhancing

Nature-based solutions can yield both climate mitigation and adaptation benefits, and there is growing recognition and support for the application of such approaches. Photo: Oyster reef installation in Mobile Bay, Alabama. Credit: Craig Guillot.

[4] The term *biodiversity-focused adaptation* has been proposed as a way of more explicitly describing and highlighting the adaptation needs of species and ecosystems themselves (Stein 2020).

resilience to contribute to sustainable development, and makes only passing reference to ecosystems. And while the concept of nature-based solutions has gained momentum within the United Nations Framework Convention on Climate Change, this is mostly from the perspective of carbon sequestration and storage (i.e., "natural climate solutions" for climate mitigation) rather than adaptation (Seddon et al. 2022). Nonetheless, to the degree that adaptation is addressed in these international accords, there is general agreement that more innovation is needed, particularly when promoted at and drawing from local-scale experiences and needs (Matos et al. 2022, UNDP 2023).

2.6. The Innovation Imperative

Given the growing pace, scale, and scope of climate change, natural resource agencies and conservation organizations will increasingly need to embed adaptation in their policies and practices. To close the gap between the current level of adaptation effort and what is needed will require a substantial ramp up in adaptation efforts—and bolder and more innovative approaches.

The solutions needed to mount a sufficient response to climate change may already exist but not yet be deployed, or they may not yet exist. Innovations can reflect modifications of a conventional approach, the hybridization of multiple existing approaches, or revival of historical or ancient approaches no longer in use. They may also draw from Indigenous knowledge and reflect long-standing traditional practices (Tribal Adaptation Menu Team 2019, OSTP and CEQ 2022). One vital component of developing innovative approaches to new challenges will be ensuring that those working to develop these ideas include diverse perspectives, worldviews, experience, and disciplinary expertise, not only from the traditions of Western science and conservation practice but also from other knowledge systems and worldviews, including those exposed to disproportionate environmental harms and risk. Indeed, centering equity in the adaptation process can, in itself, be viewed as an innovation in the practice of climate adaptation (Pelling and Garschagen 2019).

Whatever the pathways taken, adopting an innovation mindset will open up opportunities to gain insights into new approaches as well as novel applications of older ideas and practices.

Innovation is needed at all stages of the adaptation process from assessing vulnerabilities and reconsidering conservation goals, to generating ideas for action, to implementation, evaluation, and adaptive management (Section 3.3). Understanding the barriers to innovation (Chapter 5) as well as the role of enabling conditions (Chapter 6) can reveal opportunities to craft novel solutions and achieve more effective adaptation outcomes. Developing novel or untested approaches, of course, requires careful consideration of potential risks from unintended consequences of maladaptive outcomes (Chapter 7), but handled appropriately need not stymie the innovation process.

With the accelerating and cascading effects of climate-driven changes transforming ecosystems and pushing increasing numbers of species toward extinction, managers will need to move beyond the largely incremental adaptations that currently constitute the norm. There are many types, pathways, and drivers of innovation, as explored in Chapter 4, many of which will be applicable for addressing the intertwined biodiversity and climate crises. The scope and scale of this challenge requires not only the incremental adaptation advances that can be achieved by what is known as *sustaining innovations*, but a concerted effort to realize transformative adaptation facilitated through the development and deployment of truly *breakthrough innovations* (Section 4.3.2).

Managed relocation is an example of a novel adaptation strategy that is passing across the innovation lifecycle. Bull trout (Salvelinus confluentus)*, for example, have been translocated within Glacier National Park to higher elevation streams to help protect them from warming waters and other threats. Credit: Joel Sartore/National Geographic with Wade Fredenberg/USFWS.*

Chapter 3. Traversing the Innovation Lifecycle

Just as climate adaptation itself results from a deliberate process, the successful development of innovations typically results from an intentional or structured process. Indeed, process is one of the three key attributes (novelty, value, and process) embodied in our definition of innovation (Section 4.1). Although innovation is sparked by insight, creativity, and even serendipity, the importance of process and perseverance is highlighted by the inventor and innovator Thomas Edison, who famously noted, "Genius is one percent inspiration, ninety-nine percent perspiration."

This chapter explores the "innovation lifecycle," which spans the gamut from discovery, problem exploration and idea generation, to testing and refinement, through application, and on to diffusion and adoption at scale. Understanding the various phases of the innovation lifecycle provides an opportunity for policymakers, researchers, and resource managers to effectively and intentionally develop novel responses to their adaptation challenges. The chapter begins with an overview of the innovation lifecycle and its four major phases, before turning to a discussion of the so-called *valley of death*, where many innovations wither for lack of institutional commitment and investment. Finally, the chapter examines how the innovation lifecycle intersects with and can help support the various steps of the adaptation planning cycle.

3.1. The Innovation Lifecycle

Innovation is generally understood to be a result of an intentional process, which can be depicted as an *innovation lifecycle* (Figure 3.1). This framework allows us to conceptualize and understand the process for innovation from problem exploration and idea generation through to implementation and diffusion. Distinguishing among the various phases and steps of this lifecycle helps identify where there are opportunities to promote innovation by natural resource planners and managers and where barriers may exist that impede the development or application of novel ideas, including passage across the *valley of death,* where innovations are at particular risk of neglect or abandonment.

The innovation lifecycle describes a generalized process that reflects the experience of organizations, research entities, and agencies in developing and disseminating novel ideas, products, and solutions. Although discrete steps can be defined across the lifecycle (e.g., concept development, testing), we find it useful to consolidate these into four general phases: 1) problem exploration and ideation; 2) screening and refinement; 3) implementation; and 4) diffusion and adoption. Although depicted as an orderly series of phases and steps, the innovation process is not strictly linear, but instead should be viewed as a set of overlapping stages encompassing iterative cycles of ideation, refinement, implementation, and assessment. For instance, insights gained during experimentation and prototyping can inform and spark new rounds of ideation and concept development, while lessons learned during implementation of pilot projects can lead to further refinements and modification of techniques and approaches.

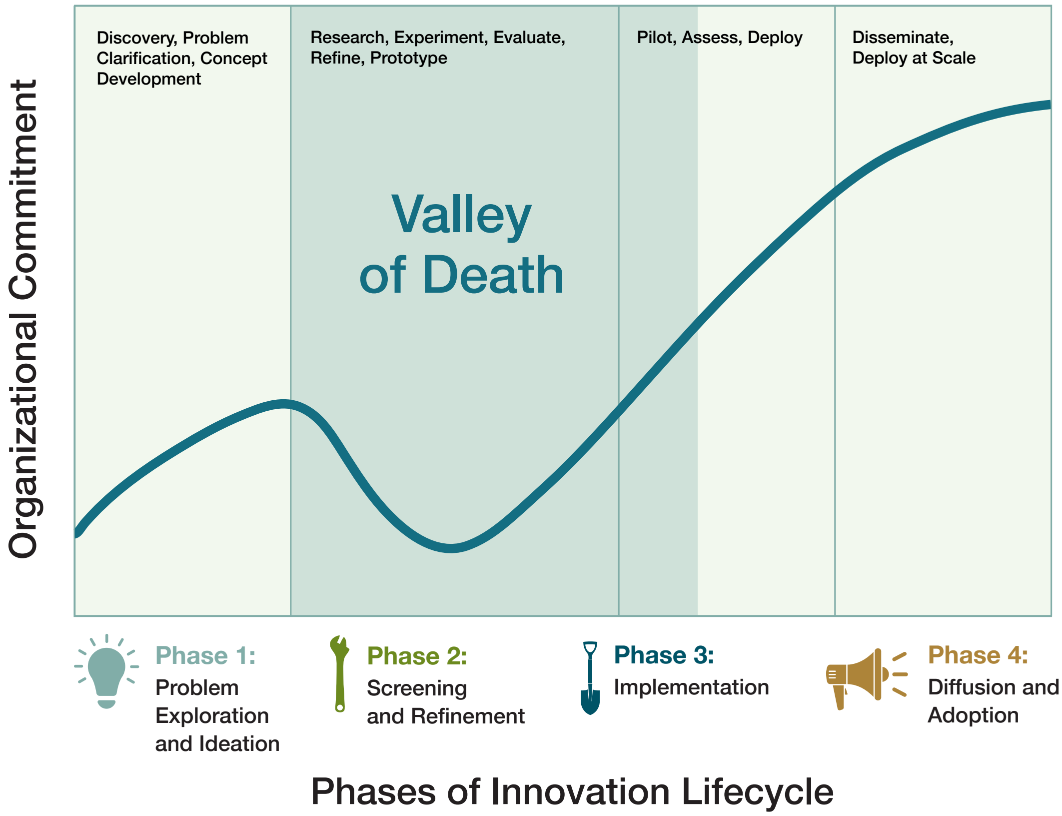


Figure 3.1. The innovation lifecycle, illustrating the four phases in the overall innovation process. The “valley of death” refers to where a gap in organizational commitment can impede the transition from concept development, testing, and refinement to deployment. The organizational commitment line (in blue) is conceptual, representing one of many possible pathways an idea may follow across the valley of death and through the innovation lifecycle (adapted from NASEM 2016).

3.1.1. Phase 1—Problem Exploration and Ideation

The first phase in the innovation lifecycle focuses on discovery, problem exploration and definition (or redefinition), idea generation, and concept elaboration. Indeed, this phase of the cycle is foundational since it is where novel ideas and possible solutions are conceived and first articulated. Crucial to solving any challenging problem is clearly defining it, and problem scoping and definition are key to virtually any intentional planning or structured decision-making process. This can include examining the problem in nontraditional ways or redefining the problem altogether. As former President Dwight Eisenhower once said, "If a problem can't be solved, enlarge it." Gaining a new understanding and definition of the problem, or recasting its context, can be key to opening up new solution sets. Indeed, recasting the problem can result from shifting from a focus on individual system components to looking more broadly at the system as a whole. Problem exploration and redefinition can also benefit from the engagement of a diverse array of participants with varied perspectives and worldviews, including those individuals and communities most affected by the issue and any potential responses (Section 6.3.2).

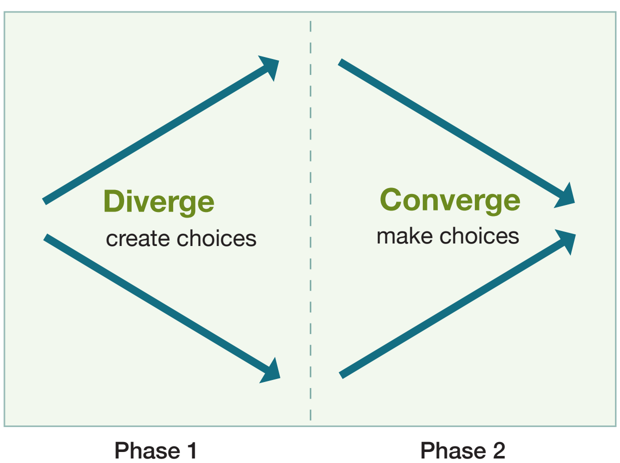


Figure 3.2. Phase 1 of the innovation cycle can be thought of as *creating choices* (left) through identifying multiple, divergent adaptation options. Phase 2, in contrast, can be thought of as *making choices* (right) by converging on promising solution sets (adapted from IDEO 2023).

Exploration and discovery are important elements of this phase since new technological tools or data can yield novel insights into both the nature of the problem as well as possible solutions. The results of that exploration and discovery process can set the stage for generating a range of possible new ideas or approaches responsive to the problem. Indeed, the goal here is to engage in *divergent thinking* by exploring and creating new choices through identifying multiple possible solutions to the problem at hand (Figure 3.2). Further exploring any promising concepts through targeted research and development efforts can then help frame and elaborate on those novel and divergent ideas and solutions.

Ideation can be a fragile process, however, and spurring creativity and unconstrained thinking is best achieved when individuals and teams are working in a safe, trusting, and nonjudgmental environment. Accordingly, creating conducive conditions and platforms for promoting exploration and ideation is crucial to this first phase of the innovation process, as described in Chapter 5.

3.1.2. Phase 2—Screening and Refinement

The second phase of the innovation lifecycle focuses on further developing, evaluating, and refining promising ideas and concepts that emerge from Phase 1. It involves sorting through the various ideas by considering their potential from diverse perspectives, including adaptation and conservation effectiveness, technical feasibility, social acceptability and equity, potential cost, and trade-offs or co-benefits with other societal or ecological values. If Phase 1 is focused on creating a set of divergent concepts, Phase 2 can be viewed as making choices by converging on the most promising ideas and solution sets (Figure 3.2). At this stage in the process, promising ideas that may have positive adaptation and conservation outcomes should not necessarily be discarded due to technical, social, or financial constraints since with additional concept development and refinement—and future shifts in the social and economic context—such feasibility constraints can evolve and resolve. Phase 2 is also where initial assessments can be made of any potential risks or maladaptive outcomes if the concept or approach were to be put into practice (Chapter 7).

Based on these reviews and evaluations, promising concepts can then be further developed and refined including, as appropriate, through experimentation, prototyping, and testing. Experimentation and learning from failure are an indispensable part of the innovation process. Indeed, rapid prototyping and quickly learning from failures has become a widely accepted best practice in the technology industry, giving rise to the concept of "fail fast"—and its counterpart of "learn fast." According to David Kelley of IDEO, to whom the "fail fast" concept is often attributed, "Enlightened trial and error beats the planning of flawless intellects."

Phase 2 is also where many innovations falter, falling into the valley of death (Section 3.2) and failing to marshal the institutional support needed to transition from the concept development and R&D stages to prototyping and implementation stages.

3.1.3. Phase 3—Implementation

Once a novel idea or approach has been successfully prototyped and tested, it is ready to move to demonstration, deployment, and broader implementation. Implementation typically starts with limited-scale deployment, often through pilot applications or demonstration projects, during which testing, assessment, and refinement may continue. As noted above, innovation is typically a nonlinear process with considerable iteration and overlap among phases. As a result, the boundaries between Phase 2 (testing and refinement) and Phase 3 (implementation) can be blurry, as can the boundaries between Phase 3 (implementation) and Phase 4 (diffusion and adoption).

Deployment of novel techniques or approaches generally requires careful monitoring and evaluation, ideally as part of an adaptive management process. This allows practitioners to assess the effectiveness of the new approach and make any needed adjustments or refinements. Monitoring to document outcomes and target thresholds also allows practitioners to look out for any unintended consequences or unexpected and unacceptable risks.

3.1.4. Phase 4—Diffusion and Adoption

The most successful innovations ultimately diffuse across a community-of-practice or entire sector and become widely adopted, often changing practice to the degree that they become part of a new normal. Phase 4 of the innovation lifecycle involves not just the application or implementation of a new concept or approach, but its adoption at scale.

To be sure, innovations that address specific problems, or the needs of particular places, ecosystems, or people, can be considered successful even if not widely adopted. Furthermore, some innovations may be successfully developed and implemented but there may be a time lag before conditions (social, economic, ecological, climatic) change to where they become more broadly relevant or socially acceptable. The concept of *managed retreat*—the strategic relocation of populations or infrastructure away from areas at high risk from flooding, erosion, or other hazards—was first articulated as a climate adaptation strategy in the 1990s,[5] but the approach was long considered socially and politically unpalatable. Although still controversial, accelerating climate-related impacts, including sea-level rise, coastal storms, and extreme flooding events, have made managed retreat a more broadly discussed and viable adaptation option, that is now being implemented in places such as Cape Hatteras National Seashore in North Carolina (Dennis 2023).

[5] Examples of what is now known as managed retreat have, however, been carried out in the United States for more than a century, particularly in response to major riverine flooding events (Pinter 2021).

Box 3.1. Managed relocation and the innovation lifecycle.

Managed relocation—also known as ***assisted migration, assisted colonization,*** or ***managed translocation***—is an innovative adaptation strategy that illustrates the passage of a new idea across the innovation lifecycle.

As climate change renders some or all of a species' current habitat unsuitable, one adaptive approach is to physically move it in order to establish populations in areas projected to be climatically suitable into the future. The translocation of species is not a new idea, and for better or worse has been occurring for millennia. What makes this idea new is the purposeful use of translocations to reduce risks from climate-related population declines through compensating for limitations in a species' intrinsic capacity to colonize newly suitable territory or assisting in surmounting extrinsic barriers (e.g., inhospitable habitat from development) that prevent unaided range shifts. More specifically, managed relocation involves "the intentional movement of biological units [populations, species, or ecosystems] from current areas of occupancy to locations where the probability of future persistence is predicted to be higher" (Richardson et al. 2009).

Phase 1. Although species translocation was suggested as a climate-related conservation strategy in the mid-1980s (e.g., Peters and Darling 1985), the idea was not fully developed and elaborated as an adaptation strategy until the mid-2000s (McLachlan et al. 2007). Like many new ideas, there has been some variation in terminology. ***Managed relocation*** was suggested as a neutral term, to clarify that the action involves purposeful species movement, and to capture a range of management actions from the initial introduction/colonization to post-establishment management.

Phase 2. Soon after the concepts of managed relocation and assisted migration were formulated, several teams of researchers and conservationists began exploring and refining the idea and assessing its implications. Hoegh-Guldberg et al. (2008) developed an evaluation framework that suggested the approach be used as a last resort after all other options are exhausted. Other groups suggested that managed relocation should be considered along with other adaptation options based on specific evaluation criteria (e.g., necessity, risk of unintended consequences, social acceptability, technical feasibility) (Richardson et al. 2009). Much of the discussion—and controversy—during this phase in concept refinement centered on exploration of risks (Mueller and Hellmann 2008, Ricciardi and Simberloff 2009). Among the key lessons from this phase of development was the importance of applying an explicit risk-based framework, including the risks of inaction, rather than rely on traditional cost-benefit analysis or the precautionary principle alone (Section 7.3.3).

Phase 3. Managed relocation is currently in the prototyping and early implementation phase. This includes both research-based experimental efforts (e.g., Etterson et al. 2020, Sáenz-Romero et al. 2021) as well as unregulated private initiatives (e.g., ***Torreya taxifolia;*** Barlow 2022). The effectiveness and sustainability of early implementation efforts are still being assessed. Some agencies already are incorporating managed relocation in their planning and management. The National Park Service, for example, has adopted an ecological risk assessment approach to evaluate potential projects (Karasov-Olson 2021), and has carried out pilot relocations (e.g., bull trout in Glacier National Park; Galloway et al. 2016).

Phase 4. Although managed relocation overall is in early days of piloting and implementation, the concept has received significant attention and is being widely adopted in some sectors. "Assisted migration" is one of the most frequently profiled climate adaptation strategies in the popular press and media. The forestry sector has broadly embraced the concept, largely because of the many decades between planting seedlings and harvesting mature trees (Pedlar et al. 2012). The British Columbia provincial government, for instance, has adopted a climate-based seed transfer strategy designed to match seedlings/seedlots to projected planting site climates (O'Neill et al. 2017). There also has been progress in modifying U.S. federal policies to facilitate the use of managed relocation, such as allowing experimental translocation of populations of federally listed endangered species beyond their historical range (USFWS 2023).

3.2. The Valley of Death

The *valley of death* refers to the challenge of moving new ideas and products from concept and design stages of the innovation lifecycle into application and actual use (Figure 3.1). In this context, the "valley" refers to a shift in the organizational commitment and resources needed to support the further development of the approach or product until it is picked up by early adopters and moves toward maturity and broader diffusion (Markham 2002, NASEM 2016). More generally, the valley of death can be viewed as a metaphor for the barriers and obstacles separating research results and operational applications (NRC 2000).

This decline in institutional commitment is usually most evident during Phase 2 and the transition to Phase 3, during which promising ideas are refined and readied for prototyping, piloting, and early implementation. It is worth noting that a drop in institutional commitment to promising new ideas or technologies is different from the abandonment of new concepts that do not hold up to scrutiny. The lack of institutional commitment or support may be due to competing pressures and funding priorities, bureaucracy, and discomfort with the prospect of ideas or tools that challenge or undermine normal business practices or status quo approaches. A lack of commitment may also be due to concerns about alignment with existing policies or legal authorities as well as concerns regarding social or political acceptability of a new approach. This can be especially true for adaptation approaches that challenge existing conservation goals that emphasize persistence of current or historical conditions, rather than transitions toward future-oriented conditions.

The difficulties of assessing the effectiveness of possible innovations represents a key challenge for crossing the valley of death, and this is especially true in the field of climate adaptation in which determining and measuring "successful" adaptation is particularly fraught (Stein and Shaw 2013, Hansen et al. 2023). Even for adaptation innovations that move into deployment phase, the journey remains difficult, and they can fall into a second valley between local-scale implementation (Phase 3) and broader diffusion and adoption (Phase 4). Unlike in many business settings, biodiversity conservation involves a broad range of actors operating in different locations at different scales and, often, quite independently. This institutional complexity requires greater attention and resources to successfully promote adoption of any particular innovation among the relevant agencies and other stakeholders (federal, state, non-governmental organizations (NGO), communities, etc.). Other issues that may hinder the adoption and diffusion of adaptation innovations include the general lack of attention within many agencies to climate-related threats (relative to more conventional stressors), as well as heightened concerns about the potential risks of adaptation actions—and underappreciation of the risks of inaction. Indeed, innovative and transformational adaptation approaches may run counter to more conventional approaches to natural resource management, which are often incentivized and well supported by existing funding and policy mechanisms. Other constraints such as limited resources, institutional capacity, and dissemination across narrow channels also make it harder for innovative climate adaptation to spread. These barriers are discussed in detail in Chapter 5.

3.2.1. Bridging the Valley of Death

There are a wide variety of reasons why promising innovations may not escape the valley of death due to a lack of institutional commitment, skepticism, and aversion to risk as noted above. Successfully crossing the valley of death requires an understanding of these possible barriers as well as opportunities for overcoming them. Indeed, Chapters 5 and 6 are devoted to exploring these barriers and the conditions for overcoming them.

Although many innovations start as part of research and development efforts (often referred to as *push* forces), harnessing the power of user-inspired *demand-pull* forces (Section 4.4.2) can be an important mechanism for transitioning from research to implementation. Engaging rights-holders and stakeholders through co-production processes can be an effective means of building interest and support for an innovation (Meadow et al. 2015, Enquist et al. 2017, Bamzai-Dodson et al. 2021). This can also be a means to harness bottom-up interest in an approach, which ultimately can find its way into top-down strategic priorities (Section 4.4.3).

Successfully crossing the valley of death requires that innovation-to-application transitioning be embedded in all aspects of project planning. Transitioning from implementation to broader diffusion can benefit from taking steps early in the process that increase the chances of an innovation being noticed, positively perceived, accessed, and tried (Dearing and Kreuter 2010, Dearing and Cox 2018). Climate adaptation interventions require adoption at multiple levels—from communities and practitioners to decision-makers at varying scales—and the reach of innovations can be accelerated and broadened by seeking potential adopters and influential individuals and organizations whose need is greatest and have sufficient capacity for adoption.

3.3. Embedding Innovation in the Adaptation Planning Cycle

As discussed in Chapter 2, innovation in the field of adaptation is urgently needed to better address the scope, scale, and pace of climate-driven changes underway that are leading to widespread ecosystem transformation. Over the past two decades there has been considerable progress in developing frameworks for more intentional adaptation planning, and several frameworks are now in wide use (e.g., Stein et al. 2014, Swanston et al. 2016, NPS 2021). The climate-smart conservation cycle (Stein et al. 2014; Figure 3.5), which has been adopted by many state and federal natural resource agencies, offers a generalized framework for adaptation planning and implementation in the context of conservation, and can serve as model for

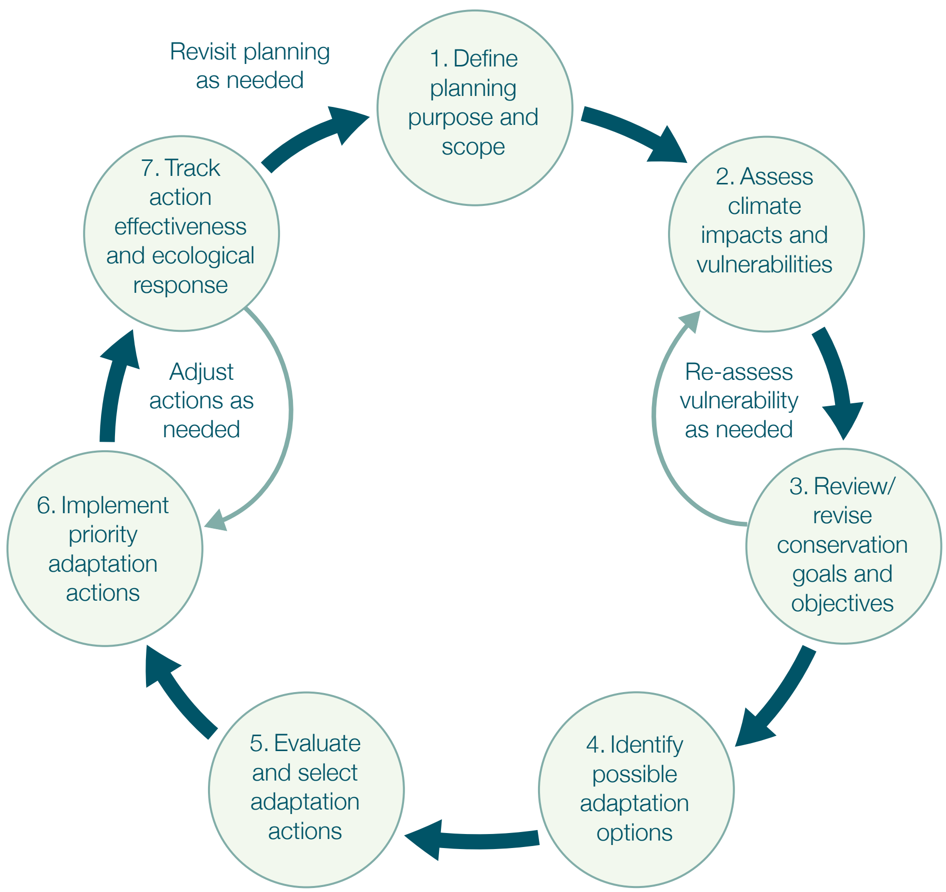


Figure 3.5. Climate-smart conservation cycle, a generalized framework for adaptation planning (from Stein et al. 2014).

understanding how the “innovation lifecycle” links to and can support biodiversity and ecosystem-focused adaptation planning and implementation.

When most people think of adaptation planning, they often jump immediately to thinking about what to do—that is, what strategies and actions can be carried out to lessen the impacts of climate change on the resources of concern (Steps 4 and 5 in the climate-smart cycle). Thinking creatively about what options and responses may be possible (i.e., Step 4), is indeed one of the parts of the cycle where innovation is most urgently needed. As described below, however, creativity and innovation are important throughout the adaptation planning cycle, not just in the identification of potential adaptation responses. The following describes where and how the innovation lifecycle intersects with the climate-smart conservation planning cycle (Figure 3.5).

Climate-Smart Step 1 (define planning purpose and scope). As with the innovation lifecycle, the climate-smart cycle begins with an exploration and definition of the problem, both in terms of nature and scope. Bringing new insights and thinking into the definition, or redefinition, of the problem can inform and open new pathways for thinking differently about solutions later in the adaptation planning process. This can often be the result of developing new and more innovative approaches (through new tools, technologies, analyses) for understanding the nature of the problem at hand. Engaging diverse stakeholders and participants in the process is critical to shedding new light on the nature of the problem, including from Indigenous perspectives and the lived experience of other groups closely tied to the resources of concern. Step 1 of the climate-smart cycle very clearly aligns with Phase 1 of the innovation lifecycle (problem exploration and ideation).

Climate-Smart Step 2 (assess climate impacts and vulnerabilities). Climate adaptation generally focuses on actions designed to reduce climate vulnerabilities and risks, and therefore a sound understanding of those risks is foundational for effective adaptation plans. A growing number of tools and datasets are available for assessing vulnerabilities under divergent scenarios of change. Although determining which resources may be most at risk is an important aspect of this, understanding why they are at risk provides the mechanistic basis for designing responsive adaptation actions. Accordingly, there is a need to enhance the application of innovative tools and analysis for understanding vulnerability, including its three components (exposure, sensitivity, and adaptive capacity). Indeed, there is a particular need for new and novel approaches for understanding and measuring the adaptive capacity and resilience of species, ecosystems, and communities as an input into the design of effective adaptation plans and actions (Thurman et al. 2020, Meek et al. 2022). Understanding the likely effect of climate changes on the systems of interest is crucial for designing effective adaptation strategies. Similarly, the problem exploration/redefinition step in Phase 1 is critical to move innovative ideas to context-specific solutions. Step 2 of the climate-smart cycle largely overlaps with Phase 1 of the innovation lifecycle, although may also overlap with research taking place during Phase 2 (screening and refinement).

Climate-Smart Step 3 (review/revise conservation goals and objectives). A core principle of climate-smart conservation is to “reconsider goals, not just strategies,” and this step of the adaptation planning process offers an opportunity to do just that in the context of projected climate-related impacts, vulnerabilities, and risks. Reconsidering underlying management goals and objectives can be challenging for many reasons, even when existing goals are clearly climate-compromised. Making existing goals more climate-informed requires the type of unconstrained and creative thinking that the innovation lifecycle is designed to promote. Indeed, this step of the climate-smart cycle forces planners and practitioners to think differently about conservation and adaptation outcomes, and how to align those with shifting ecological conditions and evolving societal values. A refinement or rearticulation of goals is foundational for the development of strategies designed to meet those goals. However, gaining buy-in for revised goals across organizational levels and with partners and other stakeholders and rights-holders can be difficult. As a result, Step 3 of the climate-smart cycle overlaps with several phases of the innovation lifecycle. Indeed, a lack of engagement and buy-in for rearticulated climate-informed goals can be a major reason potential innovations falter at the piloting and implementation levels—and are ultimately swallowed up in the valley of death.

Climate-Smart Step 4 (identify possible adaptation options). As noted earlier, Step 4 of the climate-smart process is among the most important stages in the adaptation planning process for the application of additional creativity and innovation. At this stage in the process, the goal is to identify a broad and divergent array of potential adaptation responses and solutions, unconstrained by current feasibility (feasibility and other criteria come into the process during the next step). As a result, this is a stage in the cycle where many of the techniques for ideation described in Section 4.5.3 can productively be used (e.g., brainstorming and its many variants). It is also a point in the process where it is important to create a safe space for creative and outside-the-box thinking. Although many of the ideas that are generated may not have immediate application, as conditions change (ecological, social, and financial), some ideas may become newly competitive or relevant for further development, piloting, and implementation. This stage of the process most closely aligns with Phases 1 and 2 of the innovation lifecycle, emphasizing initial idea generation and subsequent concept refinement.

Climate-Smart Step 5 (evaluate and select adaptation actions). In Step 5 of the climate-smart cycle, the broad array of adaptation options identified in Step 4 can be evaluated and compared to determine which best meet the objectives and values brought to the table by those making and affected by the decision. This includes considering the ideas and options from the perspectives of conservation, equity, and adaptation effectiveness and outcomes, feasibility from technical, social, and cost perspectives, and generation of other benefits or co-benefits. Step 5 of the climate-smart cycle aligns with Phase 2 (screening and testing) of the innovation lifecycle, and can include prototyping, testing, and refinement of the selected actions. There may be highly compelling ideas and approaches, however, that encounter various barriers to further testing and deployment and without a concerted and well-planned effort can wither in the valley of death.

Climate-Smart Step 6 (implement priority adaptation actions). Putting adaptation principles into practice requires that the priority strategies and actions identified through the planning process are actually carried out. Deployment of promising new approaches often start small with application at larger scales as managers become more familiar and comfortable with the approaches. Barriers such as concerns about uncertainties, risks, limited resources, and divergent public perception can hinder implementation of innovative approaches and need to be considered and addressed in the successful rollout of such strategies and actions. These hurdles are often higher for more transformative and breakthrough innovations (because they have fewer or no historical precedents), but can also affect incremental and sustaining innovations. Focusing on cross-sector benefits and synergies, engaging diverse partners early on, taking immediate action, but keeping sight on transformative change can help surmount those barriers to initial as well as broader implementation. Step 6 of the climate-smart cycle squarely aligns with Phases 3 (implementation) and 4 (diffusion and adoption) of the innovation lifecycle.

Climate-Smart Step 7 (track action effectiveness and ecological response). The climate-smart cycle recognizes the importance of continuous learning and iteration through monitoring, evaluation, and making needed adjustments and refinements. Although tracking effectiveness is depicted as the final step in this linear sequence, monitoring considerations should begin earlier in the process, and be applied iteratively. Crafting informative and relevant monitoring and evaluation protocols is a challenge broadly faced within the adaptation and biodiversity conservation communities. This is particularly true as practitioners seek to institute truly adaptive management approaches, and measure not just activities and outputs but adaptation and conservation outcomes. There is great need for more innovation in the development and practice of climate-informed monitoring protocols (Lynch et al. 2022). Step 6 of the climate-smart cycle does not align neatly with any particular phase in the innovation lifecycle—instead, the monitoring and adaptive management embodied in this step of the cycle can perhaps be better understood as a different type of problem to be tackled through the innovation cycle.

Artificial intelligence–enabled fire detection and monitoring sensors are being deployed around California to provide an early warning tool for wildland firefighters and emergency managers. Photo: ALERTCalifornia sensors near Santa Barbara, California. Credit: ALERTCalifornia/UC San Diego.

Chapter 4. Exploring Innovation in Theory and Practice

The term *innovation* seems to be everywhere these days, applied to everything from consumer products ("new and improved!") and computer technologies to modes of transportation and communications. Indeed, the term is used so frequently that it can sometimes be difficult to determine what it actually means and how it can and should appropriately be applied. This chapter explores the concept at a deeper level by considering the conceptual basis for innovation, frameworks for distinguishing among different types of innovation, and the processes for generating and promulgating useful innovations. Of particular note is the distinction between *sustaining innovations,* which represent incremental improvements in existing processes or functions, and *breakthrough innovations,* which can trigger significant changes in processes, behaviors, or outcomes (Section 4.3.2). Through exploring the theory and practice of innovation as developed and applied in the literature and in other sectors, we can understand how to better harness innovation to increase available options for adaptation and enhance the effectiveness of biodiversity conservation in the face of a rapidly changing climate.

4.1. Defining Innovation

Despite the broad usage of the term, there is no universal and widely agreed upon definition of innovation, and definitions can vary by sector. A typical definition is: “a new idea, method, or device: novelty; the introduction of something new” (Merriam-Webster 2023). Innovation is perhaps most frequently defined in a business context, for example: “Innovation is the systematic practice of developing and marketing breakthrough products and services for adoption by customers” (McKinsey & Company 2022), or “Business innovation is defined as the implementation of a new or improved product or business process that differs significantly from previous products or processes and that has been introduced in the market or brought into use by the firm” (NSF 2020). Perhaps the most succinct articulation of innovation from a business perspective comes from Geoffrey Nicholson, the inventor of Post-it® Notes at 3M, who famously said: “Research is the transformation of money into knowledge; innovation is the transformation of knowledge into money.”

Within the scientific community, of course, innovation is not so closely tied to economic gains or development of marketable products. The U.S. Department of Education (2004), for instance, has defined innovation as “the spark of insight that leads a scientist or inventor to investigate an issue or phenomenon.” In reviewing definitions across multiple sectors, Baregheh et al. (2008) proposed the general definition of: “Innovation is the multi-stage process whereby organizations transform ideas into new/improved products, services or processes, in order to advance, compete and differentiate themselves successfully in their marketplace.” The International Standards Organization (ISO) has issued an Innovation Management Standard that offers the somewhat abstract definition of innovation as: “a new or changed entity realizing or redistributing value” (ISO 2020).

Three broad attributes of innovation can be distilled from the literature: novelty, value, and process.

- **Novelty.** Virtually all definitions refer to a product, service, process, or entity being new, novel, or changed in some way.
- **Value.** In most definitions, it is not enough for something to be new, it must also offer some value or benefit. Although value is often measured in economic terms (particularly in the business sector), within the scientific or biodiversity conservation communities it typically would be measured in other ways, such as achieving conservation or adaptation outcomes or advancing scientific understanding.
- **Process.** Many definitions also emphasize that innovation is not just an end product, but the result of a multistage process or systematic practice.

These three attributes are concisely captured in a definition offered by Digital Intent (2023): “Innovation is the process of creating value by applying novel solutions to meaningful problems.” Building on this generalized definition, we adopt the following definition for our work to promote innovation in the field of climate adaptation:

> *Innovation is the process of creating value by developing and implementing novel solutions to climate adaptation challenges.*

The definition starts with a focus on **process**, which is also at the heart of deliberate and intentional climate adaptation. Indeed, given the continuous nature of climate change, adaptation is best understood as an ongoing process, rather than a discrete product, endpoint, or outcome. The emphasis on process in innovation is also seen in our focus on the innovation lifecycle discussed in Chapter 3, and which serves as a central framework for this guidance.

The definition’s focus on creating **value** by applying solutions to adaptation challenges is also in alignment with our overarching goal of innovation in the service of effective adaptation. As noted previously, our interest is not in promoting innovation for the sake of innovation, but rather to enhance the ability of conservation practitioners, natural resource managers, and policymakers to meaningfully address the impacts of climate change on the species and ecosystems under their stewardship. A focus on value is also consistent with other explorations of innovation in the conservation sphere. For example, in discussing innovative technology solutions for conservation, Iacona et al. (2019) emphasize the importance of explicitly identifying the value proposition an innovation would have in achieving desired conservation outcomes.

Finally, for our purposes, **novelty** and novel solutions can be understood to take various forms. Specifically, there can be truly new and novel approaches or applications, which have not been used elsewhere. Novel solutions can also include approaches or applications that transfer ideas and techniques from other sectors, regions, or communities of practice. Similarly, there may be approaches or applications that draw on or revive local, historical, or Indigenous knowledge or practices to provide just, unique, and potentially transformative solutions.

4.2. Diffusion of Innovation Theory

Among the most influential innovation theorists was E. M. Rogers, who in 1962 introduced the "diffusion of innovation" theory. This theory seeks to explain how new ideas or innovations gain momentum and diffuse through a population or social system. Rogers (2003) defines diffusion as "the process by which an innovation is communicated through certain channels over time among the members of a social system."

Adoption of an innovation occurs when a person does something differently than they had previously, and it is through this that diffusion occurs. Although these decisions vary from person to person, they are influenced by a five-step adoption process that consists of:

- **Knowledge**, where an individual becomes aware of an innovation
- **Persuasion**, when an individual forms an opinion of the innovation
- **Decision** to engage, leading to acceptance or rejection of the innovation
- **Implementation** to put an innovation to use
- **Confirmation** to evaluate the results of decision and continue its use

Perhaps the most well-known aspect of the theory is the bell-shaped graph that differentiates among five categories of innovation adopters (Figure 4.1): innovators (enthusiasts); early adopters (visionaries); early majority (pragmatists); late majority (conservatives); and laggards (skeptics). Innovators and early adopters represent a relatively small number of people who are initially open to the new idea. As early adopters spread the word, more and more people (e.g., early and late majority) become open to it and over time, the idea or product diffuses across the rest of the population until a saturation point is achieved.

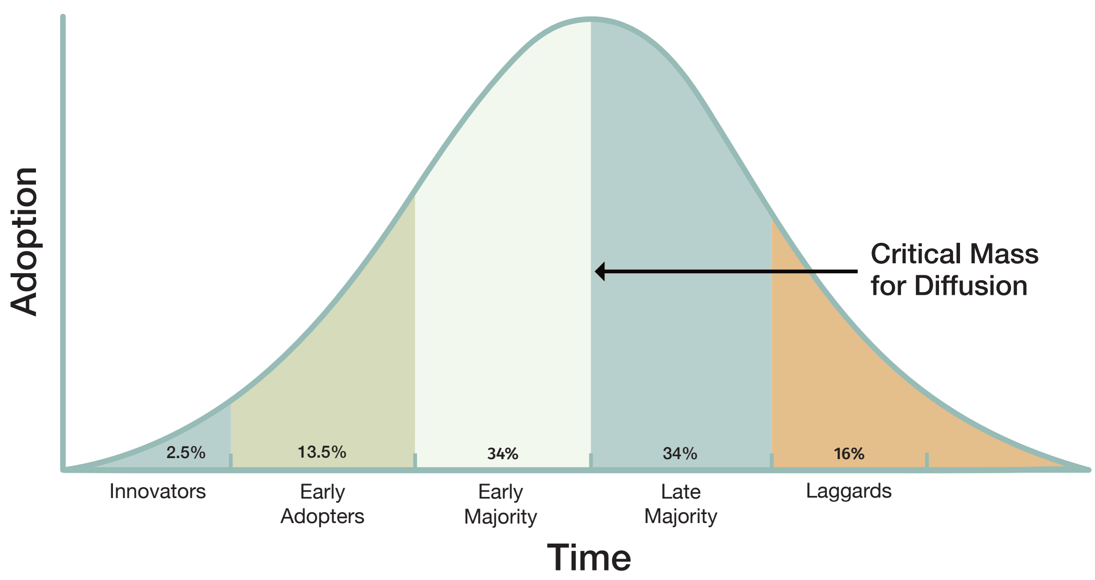


Figure 4.1. Adopter categories under Rogers' diffusion of innovation theory (adapted from Kaminski 2011).

Critical mass for diffusion is achieved when about half the population has adopted the innovation.

Rogers' diffusion of innovation theory also identifies five attributes that affect the adoption of any particular innovation. Given the predictive power of these five attributes, they are worth keeping in mind during the innovation development process, and particularly in the screening and refinement and the diffusion and adoption phases:

- **Relative advantage**—the degree to which an innovation is seen as better than the idea, program, or product it replaces
- **Compatibility**—how consistent the innovation is with the values, experiences, and needs of the potential adopters
- **Complexity**—how difficult the innovation is to understand and/or use
- **Trialability**—the extent to which the innovation can be tested or experimented with before a commitment to adopt is made
- **Observability**—the extent to which the innovation provides tangible results

4.3. Types of Innovation

The popular literature is replete with various frameworks and typologies of innovation with business articles and books offering insights into the many different types of innovation, as well as grist for cartoonists (Figure 4.2). Innovation process frameworks, while still emerging in the natural resource management literature, have been proposed and discussed in the fields of management, economics, and business for more than three decades (Costello 2015).

Some of these frameworks focus on enablers for a conducive environment to promote innovation and creativity. The "componential theory of creativity" (Amabile et al. 1996), focuses on the social and psychological components necessary for an individual to produce creative work and includes three individual-level components (domain-relevant skills, creativity-relevant processes, and task motivation) and a fourth component related to the social and work environment (Amabile 2012). The "innovation pentathlon framework" (Goffin and Mitchell 2005)

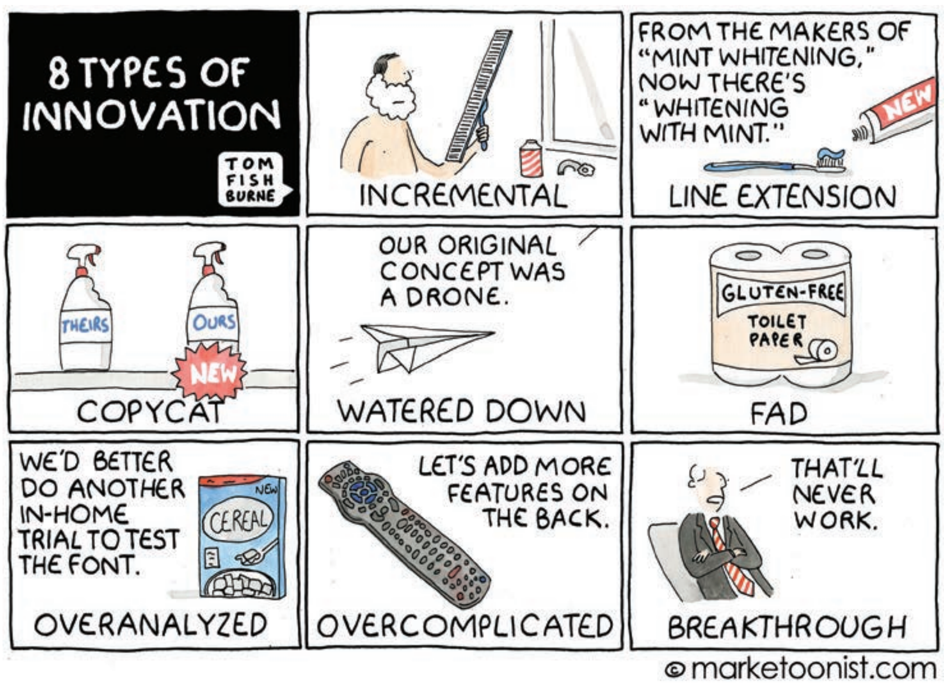


Figure 4.2. A humorous look at the proliferation of innovation types (with permission from Marketoonist).

identifies elements such as innovation strategy, ideas, and people and organization as important to innovation management. Keeley et al. (2013), in contrast, describe ten types of innovation through a business lens, ranging from profit models and product performance to customer engagement. Some frameworks depict innovation as the temporal process of turning ideas into reality—in some ways comparable to the innovation lifecycle presented above. For example, the “innovation journey” (Angle and Van de Ven 2000) divides the process of innovation into an initiation period, a development period, and an implementation/termination period, whereas the “innovation thinking process” (Basadur and Gelade 2006) consists of the four stages of generating, conceptualizing, optimizing, and implementing.

One of the most influential frameworks for promoting innovation is referred to as *design thinking* (Brown 2008, 2019). With roots in industrial design in the 1960s, it is now closely associated with the field of human-centered design and user experience. The concept of *wicked problems*—complex, multidimensional, socio-technical challenges—was part of the evolution of this solution-focused design approach (Buchanan 1992). As currently practiced, design thinking consists of a multistage process spanning inspiration, ideation, and implementation (Brown and Wyatt 2010), and broadly overlaps with the innovation lifecycle described in Chapter 3. More specifically, the process can be envisioned as the following five steps: 1) empathize (research your users’ needs); 2) define (state your users’ needs and problems); 3) ideate (challenge assumptions and create ideas); 4) prototype (start to create solutions); and 5) test (try your solutions out) (Stanford d.school 2010). The design thinking process should be thought of as a system of “overlapping spaces rather than a sequence of orderly steps,” with projects looping back through the general spheres of inspiration, ideation, and implementation (IDEO 2023).

Several authors and organizations have developed typologies of innovation that highlight different axes of interest, and we present four of these in the interest of displaying the breadth and divergence of thinking on this topic. A widely cited innovation matrix by Satell (2017; Figure 4.3a) considers innovation in the context of how well domains and problems are understood and defined. Schilling (2017; Figure 4.3b) applies a similar approach with respect to differentiating among existing and new markets and technologies. IDEO, one of the leading practitioners of “design thinking,” offers a matrix that distinguishes among existing and new offerings and existing and new users (Figure 4.3c). A typology of innovations has even been proposed in the context of sustainable development that focuses on the degree of emphasis on addressing social and environmental outcomes (Silvestre and Țîrcă 2019; Figure 4.4).

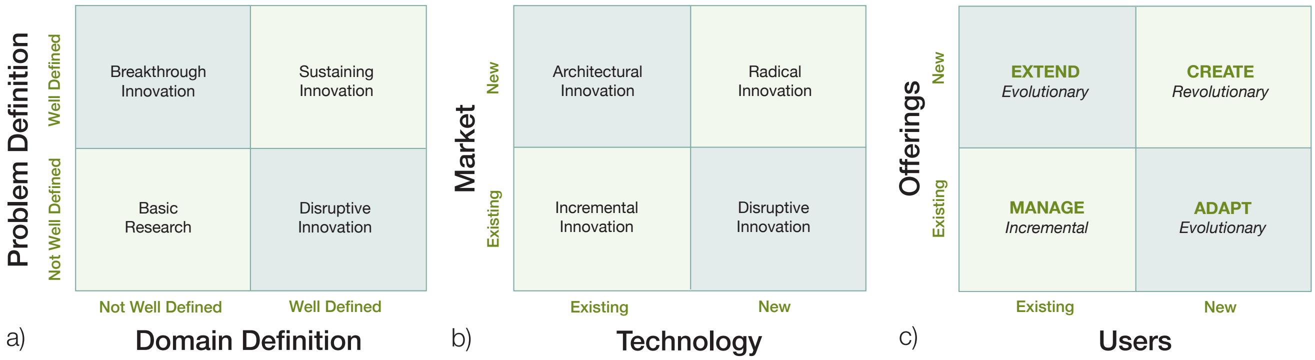


Figure 4.3. Various typologies of innovation based on: (a) problem definition and domain definition/maturity (Satell 2017); (b) market and technology (Schilling 2017); and (c) offerings and users (IDEO 2023).

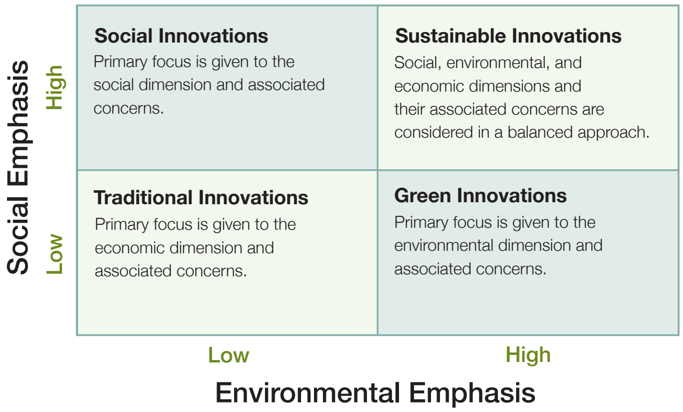


Figure 4.4. A typology of innovations from the perspective of sustainable development (Silvestre and Țîrcă 2019).

4.3.1. Disruptive Innovation

So-called "disruptive innovation" (depicted in the lower right quadrants of Figures 4.3a and 4.3b) is one of the most widely discussed types of innovation in popular culture, exemplified by companies like Uber and Airbnb that have used technological advances to shake up or "disrupt" existing industries or marketplaces. The National Academies of Science, Medicine, and Engineering (NASEM 2016) has defined *disruptive innovation* as "new ideas that trigger significant changes in systems or processes," in *contrast to sustaining innovation*, which they define as "new ideas for better operation of current systems and processes" (see next section). "Disruptive" innovations are not new, but have emerged throughout history, reflected in such shifts as from horses to motor vehicles for transportation, telegraphs to telephones to email for communications, and even from hunting/gathering to plant domestication and agriculture for food acquisition and nutrition. Unfortunately, the term *disruptive* can have a pejorative connotation that, at least within the conservation and natural resource management community, may inhibit the adoption of important and needed innovations and solutions. It is for this reason that for our purposes, we prefer to emphasize the concept of *breakthrough* innovations to refer to those novel solutions that can trigger significant changes.

4.3.2. Sustaining and Breakthrough Innovations

Although the innovation frameworks and matrices described above have useful nuances, many of the constructions are explicitly business focused and some of the categories (e.g., "architectural innovation") not intuitively obvious. We provide a glimpse of those frameworks since they can provide insights into the innovation types and processes that can be tailored for a particular organization or institution based on their climate risks and adaptation goals. For our purposes, however, we highlight *sustaining* and *breakthrough* innovations as the two high-level classes of innovation most relevant to climate adaptation for biodiversity and natural resource management.

Sustaining innovation. Sustaining innovation is the type of innovation where new ideas help in the better functioning of existing processes. This is where most innovation is likely to happen as it seeks to improve and enhance existing approaches to natural resource management. A familiarity with the problem, available skill sets, and budget and policy support make it easier to develop and implement sustaining innovations. Sustaining innovations typically would result in achieving incremental adaptation outcomes.

Breakthrough innovation. Breakthrough innovation refers to novel ideas and approaches that trigger significant changes in processes, behaviors, or outcomes. Problems that require unconventional and outside-the-box thinking often lead to breakthrough innovation. This type of innovation is essential to complex problems in the face of uncertainties that necessitates the need to look at diverse and multiple fields, skill sets, and expertise. Breakthrough innovations are more likely to result in transformational adaptation outcomes, but have the potential for higher risks and unintended consequences.

The field of biodiversity inventory and monitoring offers examples of sustaining and breakthrough innovations. For instance, technological advances in camera technologies have enabled a dramatic expansion in the use of wildlife camera traps both in professional inventories and population surveys and in community science initiatives (Burton et al. 2015). These new digital camera traps, however, are an evolution of and improvement on previous generations of camera-based survey and wildlife documentation techniques, and can therefore be considered a type of sustaining innovation. In contrast, the emergence of environmental DNA (eDNA) technologies and techniques, which allow researchers to detect the presence of organisms, including cryptic organisms, in an entirely new way, can be regarded as a truly breakthrough innovation (Beng and Corlett 2020).

4.4. Drivers of Innovation

Where innovation comes from and how it is generated are key questions in the growing field of innovation studies (Fagerberg and Vespagen 2009). The drivers of innovation can come from various directions, related to changes in the external environment, advances in the availability of research or technological tools, and shifts in societal values and aspirations.

4.4.1. System Shocks as a Stimulus

Although there are different mechanisms for how ideas move from conception to reality, one important source of innovation is shocks to an existing system. Schroeder et al. (1989), for example, found that many ideas were conceived but not acted on until some form of shock (e.g., budget crisis, product failure) stimulated action and adoption of the new approaches. Direct personal confrontations with the problem in the form of such shocks, as opposed to experiencing more gradual changes, often trigger the thresholds of dissatisfaction and discomfort needed for people to act and become more open to new ways of doing things.

Changing climatic conditions have long acted as such shocks for stimulating innovation. This includes innovations in agriculture and technology over the past few thousand years in Europe (De Dreu and van Dijk 2018), as well as changes in agricultural practice over the past century in North America (Olmstead and Rhode 2011). Massey et al. (2014) found that the impacts of extreme weather events and associated increase in public awareness of climate change impacts were the most significant drivers for climate policy innovation across 29 European countries. Similarly, major ecosystem shocks, such as widespread coral bleaching events, have been a stimulant for crafting novel approaches for coral reef protection, restoration, and adaptation (NASEM 2019).

4.4.2. Push and Pull Forces

Another set of innovation drivers can be characterized as push and pull forces. *Push forces* typically refer to advances in science or technology that open up pathways for new products or approaches that have no existing market or application. In contrast, *pull forces* (often referred to as *demand-pull*) refer to the needs of users and their interests in or demand for new ways of surmounting problems or challenges. These two forces exist in dynamic tension, since the adoption of new "push" technologies is highly dependent on meeting user needs, even if those needs were not articulated or evident beforehand.

Steve Jobs of Apple is perhaps the most well-known advocate of a push focus, saying: "Some people say, 'Give the customers what they want.' But that's not my approach. Our job is to figure out what they're going to want before they do. I think Henry Ford once said, 'If I'd asked customers what they wanted, they would have told me, "A faster horse!"' People don't know what they want until you show it to them." Successful push strategies, however, often employ a very deliberate process for understanding potential user interests, rapid prototyping, and iteratively learning from failure.

Push forces typically focus on creating new technologies or approaches and applying them to either existing or new markets or problems, whereas pull forces tend to focus on creating products or approaches meeting existing societal problems or user needs. In the context of innovation, push strategies have the potential to produce either sustaining or breakthrough innovations, whereas pull drivers are more likely to result in more incremental or sustaining innovations. That said, the two work in tandem and are both potent forces driving innovation.

Knowledge co-production has emerged as a powerful approach within the climate adaptation community for harnessing push and pull forces to produce actionable science and useful results. Co-production of knowledge can be defined as a process by which managers, policymakers, scientists, and other rights-holders/stakeholders identify specific decisions to be informed by science, and then jointly define the scope and context of the problem, research questions, methods, and outputs, make scientific inferences, and develop strategies for the appropriate use of science (Lemos and Morehouse 2005, Meadow et al. 2015, Beier et al. 2017, Enquist et al. 2017, Wall et al. 2017, Miller and Wyborn 2020). Bamzai-Dodson et al. (2021) offer a framework and guidance for engaging stakeholders in the co-production process in the context of natural resource adaptation. These authors build on Davidson's (1998) "wheel of participation" concept to describe the following spectrum of approaches for stakeholder engagement: inform, consult, participate, and empower.

Charrettes are a widely used co-production method that involve collaborative and participatory planning, often focused on architectural design and urban planning. A charrette typically involves a multiday community engagement event where rights-holders/stakeholders and decision-makers work alongside experts to explore problems and co-develop solutions (NREL 2012). Design charrettes are most often associated with the built environment, but increasingly are being applied to adaptation and resilience planning efforts (Roggema et al. 2017, Kilbane and Roös 2023).

4.4.3. Top-Down Priorities and Bottom-Up Opportunities

Another important set of drivers of innovation involves the interplay between top-down strategic priorities and investments within an organization, and the ability to take advantage of bottom-up opportunities that arise (NASEM 2016). Top-down priorities usually emerge from formal planning processes, which can include horizon-scanning and scenario planning exercises, but obviously the degree to which these plans and resulting priorities are forward-looking varies greatly across organizations and agencies. Top-down priorities tend to be expressed through the allocation and alignment of resources and investments, and if based on well-designed and forward-looking planning efforts, such top-down priorities can be successful in driving needed innovations. Unfortunately, large organizations and government agencies often are very conservative and risk averse in their planning, often constraining the ability of top-down priorities alone to drive innovation in the organization. It is for this reason that some of the most innovative ideas and work often comes from the bottom up, generated by individuals and small teams taking advantage of emerging opportunities. Such work often succeeds in producing innovation *in spite of*, rather than as a result of, higher-level strategic priorities and investments. When top-down priorities and bottom-up opportunities are aligned—for instance, through the articulation of clear strategic directions along with encouragement of creative thinking and nimble action at the individual and team level—the two together can create powerful drivers for innovation.

Push-pull and top-down/bottom-up drivers can be viewed as working in concert, as illustrated by Figure 4.5. This conceptual diagram, created as part of a National Academies study of innovation opportunities in the U.S. Air Force (NASEM 2016), recognized the important role of what they referred to as innovation

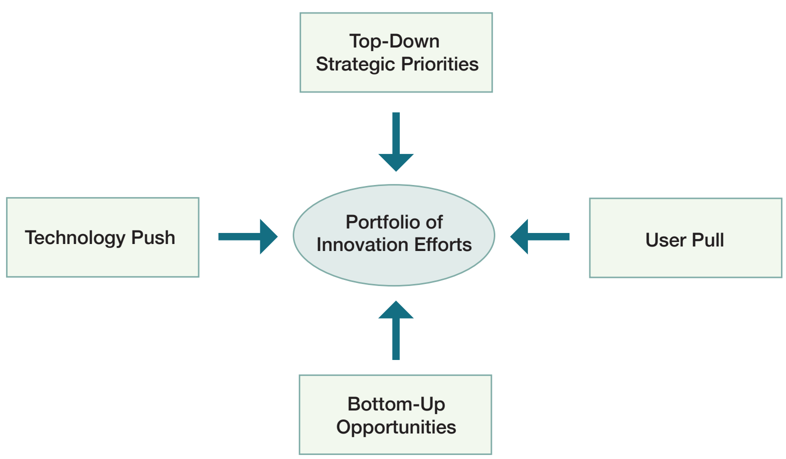


Figure 4.5. Key drivers of innovation, showing the interplay between technology push/user pull forces and top-down and bottom-up forces (adapted from NASEM 2016).

catalysts. The people designated as innovation catalysts would be responsible for balancing and blending these four forces of innovation into "portfolios of innovation efforts."

4.5. Approaches for Innovation Generation

Innovation generation relies on both knowledge creation (i.e., new information or understanding) and idea generation (i.e., new concepts for addressing particular needs or challenges). The knowledge needed to discover, invent, and innovate often involves not only existing knowledge but also the generation and acquisition of new knowledge, shared knowledge, and learning (Howells 2002). All innovations originate from ideas, and a sustainable flow of ideas is therefore central to innovation (Van de Ven 1986, Boeddrich 2004).

The source of innovative ideas typically doesn't derive from just a few individuals or a specific function. Ideation works best when informed, influenced, and shaped by individuals across scales (local, regional, national), organizations, and sectors who are directly and indirectly impacted by a problem. Well-known sources for generating innovation are universities and governments, organizations' research and development departments, and individual thought-leaders and inventors (Björk and Magnusson 2009). Climate adaptation inventions have also emerged from policy entrepreneurs where earlier stages of policy development are dominated by actors from businesses, academics, NGOs, international organizations followed by the politicians being engaged in the invention process (Jordan and Huitema 2014). Collective invention, an idea based on the free and open exchange of information, generates new knowledge while representing joint efforts at solving problems and enhancing innovation (Allen 1983).

There is a wide array of techniques, structures, and tools that can be deployed to spur idea generation and innovation. Some of these are designed to engage an entire community of practice or sector by putting out challenges or financial incentives to spur innovation. Other approaches are more structural in nature, involving the establishment of dedicated innovation teams or hubs that have the capacity and agility to focus on experimentation and rapid prototyping. Finally, there are numerous specific techniques for idea generation, which can be deployed in a variety of team and co-production settings.

4.5.1. Innovation Stimulants and Incentives

A number of techniques exist that are designed to stimulate an entire community of practice to develop new and more effective ways of addressing important issues. Many of these approaches rely on financial incentives or peer recognition as a way of spurring innovation. Specifically, there is a suite of techniques for offering grants, awards, or prizes to encourage creative thinking and novel approaches. Some of the more widely used programmatic techniques include grand challenges, catalyst and accelerator funds, and innovation prizes. Such stimulants can be useful to highlight important and emerging needs, but they have limits. Indeed, prizes and awards are often not the primary motivator for many of the most creative and innovative scientists and practitioners.

Grand challenges. Grand challenges are initiatives designed to highlight important societal problems, and to stimulate solutions through engaging broad communities of practice and harnessing science, technology, and innovation. Federal agencies such as the National Science Foundation, Department of Energy, and NASA make extensive use of this technique to raise the profile of major problems, particularly those with the potential to capture the public's imagination. The U.S. Government's challenge.gov website offers a comprehensive list of grand challenges and innovation prizes offered by federal agencies. Grand challenges can also be organized by private sector and philanthropic organizations. For instance, Conservation X Labs spearheads a number of conservation-related grand challenges, which are coupled with the use of directed accelerator funds (discussed next).

Catalyst and accelerator funds. Catalyst and accelerator funds are often used as a way of encouraging work and investment in promising new approaches or technologies. This type of funding is typically focused on encouraging implementation among early adopters and demonstrating the viability of new approaches or technologies. Although most commonly associated with the technology and business sectors, especially through the use of venture capital, catalyst and accelerator funds are increasingly being deployed for conservation and adaptation-related efforts, such as the Wildlife Conservation Society's Climate Adaptation Fund, the Nature+ Accelerator Fund, and the UNDP Adaptation Fund Climate Innovation Accelerator.

Innovation prizes. Innovation prizes are an increasingly popular means for private philanthropies and others to encourage and elevate potentially transformative work on various societal and environmental challenges. These prizes may be global in scale, such as the Earthshot Prize, or more limited in geographic or sectoral scope. For instance, the IUCN-Species Survival Commission runs the George Rabb Award for Conservation Innovation, while the U.S. Fish and Wildlife Service has instituted a Theodore Roosevelt Genius Prize to promote innovation in addressing several critical wildlife conservation issues.

4.5.2. Innovation Incubators

The creation of dedicated teams to focus on experimentation and rapid prototyping (and what is sometimes referred to in the software field as lean development) of new products and technologies has been a successful approach to incubating innovation in the corporate world. The archetype for such efforts is Lockheed Martin's famous Skunk Works®, established during World War II and charged with developing jet fighter planes. The term "skunkworks" now is often used generically to refer to research and development units that have a high degree of autonomy within an organization and are given the resources and agility needed to innovate (Brown 2004, Oltra et al. 2019). Other prominent examples of dedicated innovation units include Google's X Development lab, Xerox's PARC (Palo Alto Research Center), and even Taco Bell's Innovation Kitchen (Hitchens 2023). Not only do such dedicated teams tend to have a high level of flexibility and independence, but by working outside standard hierarchies they can more easily explore transformational or disruptive approaches that may be perceived as threatening to entrenched interests or normal business practices (Fosfuri and Rønde 2009).

Dedicated innovation teams have also been employed within the biodiversity conservation community, both within individual organizations as well as cross-organizational efforts. For example, the Science for Nature and People Partnership (a collaboration of The Nature Conservancy and Wildlife Conservation Society) supports multidisciplinary working groups that convene around specific global challenges at the intersection of conservation and human well-being. In other instances, entire organizations are organized around the concept of innovation, including the Environmental Policy Innovation Center, whereas other organizations have created innovation-branded internal units, such as Defenders of Wildlife's Center for Conservation Innovation or the Chesapeake Conservancy's Conservation Innovation Center.

4.5.3. Ideation Techniques

There is a wide array of techniques for facilitating idea generation as an input to strategic planning processes, product development, and scientific exploration and discovery. While many of these can be carried out as internal team exercises, there is also power to engaging end users and diverse audiences in co-creation workshops or exercises. Indeed, knowledge co-production through collaboration with and engagement of end users (e.g., on-the-ground resource managers) is particularly useful in the problem exploration and ideation stage of the innovation process. Techniques for ideation are extensively covered in the literature (e.g., Osborn 1957, White et al. 2012, Daly et al. 2016) and in numerous online "how to" guides and blog posts, including by such organizations as the Interaction Design Foundation and IDEO.

Brainstorming is probably the most widely used technique for ideation. This is a team exercise intended to generate a large number of ideas quickly through participants verbally offering up possible solutions. Some of the core principles for effective brainstorming are: come up with as many ideas as you can; don't criticize other ideas; freewheel and share wild ideas; and expand and elaborate on existing ideas (Osborn 1957). There are also a number of brainstorming variants, such as brainwrite, braindump, brainsketch, brainwalk, and crowdstorm. The SCAMPER method is another useful approach that can help in the ideation process by looking at a problem through a series of directed, idea-spurring questions (Serrat 2017). The lenses associated with this method are: substitute, combine, adapt, modify, put to another use, eliminate, and rearrange. It is beyond our scope to describe and review the wide array of ideation techniques, but other methods include: worst possible idea, challenge assumption, mind mapping, sketch storm, storyboard, five whys, crazy 8s, and six hats.

Box 4.1. Fostering creativity with Oblique Strategies cards.

The musician/artist Brian Eno and multimedia artist Peter Schmidt introduced the concept of Oblique Strategies cards in 1974 as a tool for fostering creativity in artists, and especially musicians. When confronted with a dilemma, a musician or artist could draw a card and follow its instructions even if its appropriateness is unclear. Example cards included "discard an axiom" or "work at a different speed." An original motivation for Eno was to have a tool to help him avoid too much focus on a "direct head-on approach" to a problem: "If you're in a panic, you tend to take the head-on approach because it seems to be the one that's going to yield the best results. Of course, that often isn't the case—it's just the most obvious and apparently reliable method." While originally produced in a small quantity, the cards went through a number of printings and expansions of the deck and have been used by a variety of artists, including David Bowie (when working with Eno), Coldplay, and the B-52s.

4.6. Learning from Failure

Experimentation and productively learning from failures are among the most important elements of the innovation process. In a National Academies review of best practices of innovative organizations, virtually all had cultures where risk-taking was accepted and failure tolerated along the way to ultimate success (NASEM 2016). As noted above, the Silicon Valley mantra of "fail fast" is an articulation of the value placed on experimentation, rapid prototyping, and productively learning from failure. In an entirely different context, chef José Andrés, the humanitarian founder of World Central Kitchen, which offers meals in disaster zones around the globe, notes that, "Success is going from failure to failure without losing enthusiasm…we keep adapting and trying."

Learning from failure is equally important in the biodiversity conservation and natural resource management space, and is at the heart of adaptive management concepts. That said, there are particular challenges in applying the concept of "fail fast" within the biodiversity/ecosystem adaptation domain. First, although adaptive management is widely regarded as the gold standard for natural resource management, it is challenging to apply in practice and there are relatively few rigorous applications of the technique. Second, many ecological and natural resource management experiments take considerable time to carry out, which makes it difficult to embrace a "fail-fast" ethos. Third, there are considerable institutional and cultural barriers (discussed in Chapter 5) to admitting failure. That said, see Chapter 6 for discussions of how an institution's willingness to learn from failures can be a key enabling condition for supporting innovation.

A variety of barriers can impede the development and adoption of innovative adaptation approaches. Photo: Pronghorn (Antilocapra americana) *stopped by barbed-wire fence near Encampment, Wyoming. Credit: Richard Ellis/Alamy.*

Chapter 5. Barriers to Innovation

By its very nature, innovation involves doing things differently. Although this can lead to substantive—and even transformational—improvements in various aspects of our lives and in our conservation effectiveness, breaking out of comfortable routines, business-as-usual practices, and conventional ways of thinking can be daunting. Promoting successful innovation depends on finding ways to surmount these and other hurdles. To help do so, this chapter explores a few of the key barriers that can impede the development and adoption of innovations, with particular focus on innovations in the realm of biodiversity and ecosystem adaptation. Our purpose in examining these barriers is not to dwell on how difficult it is to innovate, but rather to provide context for how these barriers can affect the innovation lifecycle and be overcome through the "enabling conditions" described in Chapter 6.

We consciously refer to these as *barriers*, since they represent hurdles that can be surmounted with focused effort. This is comparable to the distinction drawn in literature between adaptation barriers and adaptation limits. Moser and Ekstrom (2010), for instance, characterize *adaptation barriers* as obstacles that can be overcome with concerted effort, including "creative management, [and] change of thinking" (in other words, innovation). In contrast, *adaptation limits* are defined as hard boundaries beyond which existing activities, systems, or resources cannot be maintained and would suffer irreversible loss and/or radical system shifts (Moser and Ekstrom 2010).

There is extensive literature on barriers to innovation as well as to adaptation. The innovation barriers highlighted here draw from this literature and were informed by the experience of workgroup members, as well as input from participants at a 2022 National Adaptation Forum workshop. This chapter explores four general categories encompassing 15 key barriers:

Institutional Barriers
- Risk aversion
- Unsupportive institutional culture
- Lack of incentives
- Restrictive regulations and policies

Social Barriers
- Operating in silos
- Lack of diversity
- Power dynamics
- Conflicting values

Knowledge and Learning Barriers
- Limited knowledge
- Resistance to new ideas
- Evidence for effectiveness
- Poor knowledge transfer

Capacity Barriers
- Lack of time
- Limited financial capacity
- Limited human capacity

5.1. Institutional Barriers

Although innovation is a highly valued trait in the abstract, many aspects of institutional culture can act as a disincentive to creative thought and innovative practice. Innovation is a product of work by individuals, teams, organizations, and networks, and institutional barriers can operate at each of these levels. Additionally, because of the continued politicization of climate change, efforts to address climate-related risks through adaptation actions—whether based on novel approaches or existing strategies—can face internal and external barriers and opposition. We focus on four barriers to explore the role of institutional culture in impeding innovative adaptation:

- Risk aversion
- Unsupportive institutional culture
- Lack of incentives
- Restrictive regulations and policies

5.1.1. Risk Aversion

Aversion to taking risks is one of the most significant barriers to innovation in the biodiversity conservation and adaptation spheres. Risk aversion can manifest itself at both the level of the individual (personal discomfort) as well as the organization (culture and business practices to avoid or minimize risks). There are, of course, many legitimate reasons to be concerned about the risk of adopting new technologies or approaches, paramount among them the possibility of adverse consequences, whether anticipated or unintended. Both individuals and institutions can have varying risk tolerance profiles, with some being more or less open or averse to taking risks. Natural resource management agencies often are quite risk averse, with decision-makers cautious about or unwilling to accept uncertain outcomes (Borchers 2005, Tulloch et al. 2015). In addition to concerns about possible adverse consequences, agencies can also be uncomfortable with the uncertainty of outcomes. As a result, they may opt to invest in work having lower expected benefits but higher certainty of success in achieving those outcomes (Tulloch et al. 2015). Indeed, under many existing statutes, such as the Endangered Species Act, there is no penalty or consequence for failure to act or intervene; rather, consequences are mostly associated with acting in ways that are deemed to harm or adversely affect a protected resource. These general tendencies for risk aversion are only accentuated in responding to climate-related impacts, since adaptation is still a new concept for most agencies and climate change introduces a different level of uncertainty into their decision-making processes.

The widespread application of the "precautionary principle" within the environmental community is another factor that may contribute to risk aversion. As described in more detail in Chapter 7, the principle was developed as a way to avoid undue risk in the face of large scientific uncertainties, and emphasizes a "do no harm" approach. Unfortunately, applied in its most restrictive manner, the principle can have a stifling effect on innovation (Bourguignon 2015, Hemphill 2020). Additionally, unlike more traditional risk assessment and management techniques, application of the precautionary principle tends to ignore the risks of inaction (Schwartz et al. 2009).

Risk aversion can be most pronounced at the middle and later stages of the innovation lifecycle, particularly when there is little yet known about the costs, benefits, and consequences of a new idea or practice. A low risk tolerance among organizational leaders can constrain the ability to attract the institutional support and funding needed to move an idea into and through testing, refinement, and prototyping and to traverse the infamous valley of death. Promising innovations can also face hurdles in their implementation due to risk aversion among stakeholders and affected communities. This can be due to concerns about adverse effects, competing or conflicting values, historical inequities, as well as a lack of concern about the underlying climate-related problem, or recognition of the risks of inaction. Addressing these concerns can require a considerable expenditure of an organization's political capital.

5.1.2. Unsupportive Institutional Culture

There are many ways in which institutional cultures can be unsupportive of innovation and impede creativity among staff. Organizations and agencies in the field of natural resource management can be slow to recognize new problems and adopt new ways of doing things. Although most conservation agencies and organizations embrace adaptive management conceptually, at an operational level many agencies continue to emphasize "doing things the way we've always done them." This can be due in part to a fear of failure at both staff and leadership levels (Meek et al. 2015). The repercussions for staff (and leadership) trying something new and failing can often be greater than applying accepted practices that may be ineffective or result in the continued decline or loss of a valued resource.

Measures of staff and organizational performance can contribute to a culture unsupportive of innovation. It is much easier to measure the completion of specific tasks and activities (i.e., outputs) than the achievement of desired goals or conservation outcomes. As a result, success is often measured by the number of tasks completed (e.g., acres treated) rather than by the efficacy of those activities. Even the nature of research and monitoring carried out by an organization can contribute to this disconnect. Whereas researchers in the academic sector often focus on critiquing or disproving hypotheses posed by other researchers, agency-sponsored research can at times focus more on validating existing approaches and practices than on scrutinizing underlying assumptions and outcomes. Indeed, the increasing calls for evidence-based conservation go to the heart of making public and private sector organizations more effective and accountable for the efficacy of their investments (Sutherland et al. 2004).

The continued politicization of climate change, especially in some regions of the United States, can exacerbate these more general institutional barriers to innovation. This is particularly true of state-level agencies where there may be high-level (i.e., governor's office) denial of the reality of human-caused climate change. Indeed, Yocum et al. (2022) found that the leadership of a state fish and wildlife agency could either facilitate or hinder the use of climate change information in their state wildlife action plans.

An unsupportive agency culture can pose barriers across the innovation lifecycle, starting with an open exploration of the nature of the problem (especially in places where climate change remains a politically charged issue). Innovations that can be viewed as displacing existing business practices (what NASEM [2016] termed the *normal production organization*) can also meet resistance in transitioning across the valley of death from prototyping and testing to implementation (Phase 2 to 3) (see Section 3.2).

5.1.3. Lack of Incentives

A specific aspect of an unsupportive institutional culture is the lack of incentives for staff to engage in creative and outside-the-box thinking and action. At an organizational level, incentives can range from monetary benefits (salaries, bonuses) to various forms of recognition, including awards, patents, or publications. This barrier also takes the form of a lack of time (especially flexible time) (Section 5.4.1) and institutional resources to engage in fresh thinking about existing problems and to experimentation and testing of new ideas. And while many public and private funding agencies say that they value innovation, the way in which most grants and awards are structured does not incentivize exploration, discovery, and innovation. Overly strict requirements for detailed workplans, activity lists, and timelines across multi-year awards can motivate applicants and funders to focus on safer, existing approaches rather than experiment with more agile and innovative approaches that may have a higher risk of failure and less well-defined timelines and benchmarks.

Incentives, or lack thereof, can stimulate or inhibit innovation as it moves through the innovation lifecycle. Research related to climate adaptation needs to be done in the light of uncertainties and adaptive management, and while short-term, project-based incentives and investments can be useful, longer-term programmatic incentives are more likely to instill a culture of creativity and innovation in an organization. Furthermore, communities and end users and other stakeholders, particularly from burdened and underserved groups, might require additional incentives (e.g., financial, recognition, identification of collateral benefits) to meaningfully engage in climate adaptation planning efforts generally, and innovation development efforts specifically.

5.1.4. Restrictive Regulations and Policies

Climate adaptation, as with all other activities, must be carried out within the bounds of existing laws, regulations, and policies (McDonald and McCormack 2021). Unfortunately, many of those legal and regulatory frameworks emerged under assumptions of climatic stationarity and environmental constancy, and are tied to historical benchmarks. Even apart from changing climatic conditions, many so-called "command and control" regulations are poorly equipped to allow for and support flexible and adaptive approaches to the management of dynamic ecosystems (Ruhl 2005). Rigid legal and regulatory frameworks may also pose challenges for the development and application of innovative adaptation approaches. The barriers to innovation will be particularly noticeable in instances where laws and associated regulations are both prescriptive and tied to historical data or baselines (Hiers et al. 2016).

There is often more flexibility in the interpretation of laws, regulations, and policies than many resource managers may assume, however. Similarly, laws and regulations are not immutable, and changes in interpretations or formulations can and do occur. In order of difficulty, institutional policies can be modified, regulations updated, and even laws amended or repealed. As an example, many U.S. Endangered Species Act regulations are linked to historical species ranges and current habitat occupancy. These policies and regulations have long been interpreted as limiting the ability of managers to proactively move listed species outside of their historical ranges. The U.S. Fish and Wildlife Service has recently updated its regulations regarding "experimental populations," which now explicitly allows for the translocation of listed species outside of their historical range (USFWS 2023). This change was made, in large part, to offer more flexibility in translocating species to track suitable climatic conditions, itself a climate adaptation response.

Legal and regulatory constraints can especially affect Phases 3 and 4 of the innovation lifecycle, where new solutions move through testing to implementation. Innovative adaptation measures, such as various nature-based solutions, continue to face implementation barriers due to unconducive or restrictive regulations and policies that often favor traditional structural approaches to hazard mitigation. Cost-benefit rules in particular often put natural and nature-based features at a disadvantage relative to engineered solutions, in part because of the historic difficulties in assigning value to ecosystem services (Dailey et al. 2009)[6] and in part because of uncertainty regarding efficacy (Section 5.3.3).

[6] The U.S. Government has recently released draft guidance for incorporating ecosystem services into cost-benefit analyses carried out by federal agencies: https://www.whitehouse.gov/wp-content/uploads/2023/08/DraftESGuidance.pdf

5.2. Social Barriers

Beyond the institutional issues described above, there are a number of broader social barriers that can constrain the development and application of useful innovations in a conservation and adaptation context. The raw material for innovation includes diverse perspectives, new knowledge, and novel insights into both problems and solutions. In particular, exploring the problem from new angles and generating varied and divergent ideas can benefit from the involvement of teams with diverse experiences, perspectives, and disciplinary expertise. Social barriers, however, can lead to unhealthy echo chambers that limit such engagement, and can constrain both the development of novel ideas and the likelihood of their successful implementation and adoption at scale. We explore four social barriers:

- Operating in silos
- Lack of diversity
- Power dynamics
- Conflicting values

5.2.1. Operating in Silos

Thinking differently is key to coming to new understandings of a problem and crafting new approaches for its solution. Accordingly, operating in disciplinary or organizational silos can impede innovation, and lead to constrained thinking or a "silo mentality" (de Waal 2019). Teams that all come from a particular disciplinary or technical background may be more likely to be convergent rather than divergent in their thinking or decision-making (Mukherjee et al. 2016). Disciplinary silos can arise within a given organization or agency, as well as across a broader community of practice. For example, looking at a problem from only one perspective (e.g., a single species or one ecosystem service) may miss broader system-level considerations, including other relevant ecological or social (i.e., human dimension) factors.

Working in silos can accentuate competitive interactions, whether the silos comprise vertical divisions or departments, teams within horizontal functions, or among organizations, academic disciplines, and communities of practice. Poor collaboration across teams can make it hard to share relevant knowledge and insights and create innovations that are likely to have broader applicability and wider acceptance. Indeed, the "not-invented-here" syndrome is a major impediment to the diffusion and adoption of new ideas and approaches (Antons et al. 2017). Different agency missions, jurisdictions, and cultures also contribute to the creation of silos in the natural resource management community, and within many agencies and organizations there is also a gap between the research and management branches.

Collaborations and partnerships can be especially important in driving innovation by bringing together varied knowledge, expertise, disciplines, and experiences (Berger-Tal and Lahoz-Monfort 2018). A lack of collaboration can also impede the diffusion of new ideas and conceptual innovations. For example, weak engagement with the business sector and a perceived lack of "practical fit" has hampered the broader uptake of the ecosystem services concept (Stevenson et al. 2021), while a lack of collaboration between research entities and private firms can lead to a mismatch between the technology developed in labs and those needed for application (Zanello et al. 2016).

Climate adaptation and biodiversity conservation require diverse perspectives (ecological science, social sciences, engineering, legal and policy) and collaboration among organizations at multiple levels (federal, state, local) and across sectors (nonprofits, for-profits, private landowners, community-based groups). Boundary organizations, which operate at the interface of science and policy, can be helpful in knowledge co-production and in translating user needs for researchers and relevant science for decision-makers (Guston 2001, Safford et al. 2017, Gustaffson and Lidskog 2018). This web of organizational and disciplinary interactions, if lacking, impacts all phases of innovation from problem exploration and ideation to implementation and adoption. Unusual and creative adaptation solutions can be entirely missed in early phases if individuals are working independently, and can fall out of Phase 2 evaluations if varied perspectives are not engaged in the screening and refinement. The ideas emerging from a narrow, single-silo perspective consequently may fail to achieve broad acceptance during implementation and adoption phases of the cycle.

5.2.2. Lack of Diversity

Diverse perspectives and expertise, as noted earlier, provide a holistic and more expansive basis for imagining novel and creative solutions to adaptation challenges. As a result, a lack of diversity can seriously constrain the development and successful deployment of new and innovative adaptation solutions (Morrison and Steltzer 2021, Wailoo et al. 2023). There is growing evidence for the importance of diversity in the innovation process. Hong and Page (2004), for example, found that groups of diverse problem solvers outperformed groups of "high-ability" problem solvers. Diversity generally refers to differences in demographic characteristics, cultural identities and ethnicity, and training and expertise. Such differences in identity are linked to what can be called *functional diversity*, referring to differences in how people represent problems and go about solving them (Hong and Page 2004). Other researchers have explored the role of diversity more generally in scientific innovation. Hofstra et al. (2020), for instance, reviewed nearly 40 years of Ph.D. dissertations and found that underrepresented groups produce higher rates of scientific novelty, but that their novel contributions were often devalued and discounted. The business case for a commitment to diversity is also well demonstrated, including by comparisons of organizations' financial performance (e.g., Slater et al. 2008). By introducing new voices and perspectives, organizations are better able to understand and address the needs of demographically diverse stakeholders, while also stimulating and harnessing greater innovation (Slater et al. 2008).

Lack of diversity can constrain the development of innovations at several levels. First, a lack of diversity on the core planning or innovation teams can limit the different perspectives represented on the team, constraining the number and type of divergent ideas, as well as how those ideas may be evaluated and advanced. Who is "at the table" during participatory planning processes also matters, and a lack of diversity among stakeholders and rights-holders engaged at various stages in the process can have consequences. For example, without understanding diverse views, values, and knowledge systems, the team may miss different insights and formulations for the nature of the problem, exclude creative ideas for solutions, or fail to recognize key issues related to the social acceptability of possible solutions and community perceptions of risk. Indeed, engagement of diverse and relevant stakeholders is particularly important for gaining the trust and buy-in needed to move from research to implementation and to putting novel adaptation options on the ground. There are also risks, however, of engaging with diverse stakeholders and rights-holders in ways that are, or appear to participants, as being inauthentic, performative, or culturally disrespectful. Diversity considerations should explore representation of the full array of relevant rights-holder/stakeholder demographics, which depending on place and issue could include different cultures, ethnicities, economic statuses, religions, ages, sexual orientations, gender identities, as well as various disabilities and neurodiversity.

Climate change often imposes disproportionate impacts on different population groups, including socially and economically vulnerable populations. Effective adaptation may require intentionally centering the perspectives and leadership of otherwise underrepresented groups. Historical and current inequities faced by marginalized communities, and resulting legacies of mistrust of governing agencies may result in low stakeholder participation, including poor participation during consultations, or lack of participation at all. Similarly, social or cultural norms, political ideologies, public perception, and peer pressure may result in poor trust, low engagement, and failure to gain the stakeholder involvement and input needed. This is of particular concern for the conceptualization, diffusion, and uptake phases of the innovation lifecycle. Marginalization of active and engaged rights-holders and stakeholders presents an additional barrier, for example through poorly led engagements that exclude them from dialogue or fail to integrate their inputs (Blok 2014).

5.2.3. Power Dynamics

Different stakeholder and rights-holder groups are more or less connected to power and decision-making. Some of these differences arise from systemic biases and barriers that increase (or diminish) opportunities for some groups to attain status and positions of power and to have their perspectives heard. Other differences are inherent to various roles, such as decision-makers, policymakers, managers, community members, or subject experts. As a result, some stakeholders are more powerful than others in defining problems, risks, and potential solutions while the voices of others may be ignored (Blok 2014). When more powerful actors disrupt, obstruct, or mislead the process, this asymmetrical distribution of power can derail stakeholder engagement, posing significant risks to the legitimacy of the process and a major barrier to innovation (Thapa et al. 2019). In a context of strong organizational or individual leadership, however, responsible facilitation, group communication, and negotiation can manage and minimize such risks.

When leading, designing, and evaluating any climate adaptation intervention, the dynamics of stakeholder engagement and participants' inherent biases should be considered during all phases of the innovation lifecycle. Those who bear the brunt of cumulative climate and biodiversity impacts may feel invalidated, and their ideas excluded, by more influential individuals or organizations, which can reinforce their marginalization and vulnerability. Even in well-intentioned adaptation efforts where ideas from all groups are brought to the table, power dynamics can lead to a preference for advancing options advocated by more influential individuals and organizations.

5.2.4. Conflicting Values

Since values underpin decision-making and goal setting at both individual and institutional levels, differences or conflicts among values can pose a potential barrier across the innovation lifecycle. Underlying values among stakeholders and rights-holders may not be well understood or articulated, potentially adding a further layer of misunderstanding and source of conflict. Societies frequently hold heterogeneous social norms, or "moral pluralism" (Thapa et al. 2019); for example, commercial interests may oppose certain broader societal or environmental values even while commercial and nonprofit organizations coexist. Such inconsistencies and conflicts are inevitable.

Trade-offs are inherent to any process, including climate adaptation where climate change affects various individuals or populations differently, and often concurrently. Choosing an adaptation option requires inclusion of multiple perspectives to consider the broad array of its potential risks and benefits to the population it aims to serve. Excluding conflicting views and generating and screening ideas with only a narrow set of stakeholder perspectives and without considering all its potential trade-offs (including both expected and unanticipated adverse consequences) can hamper the adoption and broad diffusion of innovation. Limited understanding of, or ability to influence (Björklund 2018), community values and cross-sectoral impacts is an important barrier in the earliest and later phases of innovation, as it can again limit community or stakeholder acceptance of plans and decisions to implement innovative interventions. Prober et al. (2019) highlight the need for community consultation in setting goals as one of the key paths for effective climate adaptation in nature conservation, and highlight examples such as potential for poor uptake of novel fire management approaches due to lack of community understanding about potential benefits of fire.

5.3. Knowledge and Learning Barriers

Knowledge and learning underpin the potential for developing innovative ideas and approaches in biodiversity-focused climate adaptation. A sound understanding of ecological system functioning, as well as current and future stressors to those systems, serves as the basis for clearly defining problems and identifying potential solutions, while an understanding of social and economic factors can be key to selecting actions likely to be both effective and suitable for broad implementation and uptake. On the basis of a literature review and workgroup experience, we explore four classes of knowledge and learning barriers that can constrain the development and implementation of innovative adaptation actions. We note, however, that in many cases these knowledge barriers interact with other types of institutional, social, and capacity barriers.

- Limited knowledge
- Resistance to new ideas
- Evidence of effectiveness
- Poor knowledge transfer

5.3.1. Limited Knowledge

Crafting effective adaptation responses depends on a robust understanding of natural and social systems. Innovation can be constrained by limited knowledge of biophysical factors, technical/management options, human dimensions, and interactions among all these.

Biophysical knowledge. Biophysical knowledge includes information about organisms, ecosystems, disturbance regimes, and competitive interactions, as well as relevant environmental variables such as soils, hydrology, and climate. Innovation in adaptation can be limited by multiple types of biophysical knowledge gaps and uncertainties, including climatic projections (especially at regional and local scales), responses of ecosystems and species to projected climatic changes, and potential species or ecosystem responses to different management interventions or to human responses to climate change. For example, suitable management interventions could vary widely depending on whether moderate or substantial changes in temperature or precipitation are expected, and whether species and ecosystems are thought to have the potential to persist under those conditions (i.e., high adaptive capacity). Indeed, understanding the adaptive capacity (or resilience) of species and ecosystems—and the type and degree of change they can be expected to tolerate—is one of the key knowledge limitations affecting contemporary adaptation planning (Dawson et al. 2011, Thurman et al. 2020). Another major source of uncertainty comes from the path-dependency of ecological change, with future realizations contingent on the timing and sequence of particular events (climate extremes, mortality events, recruitment pulses) (Bradford et al. 2018, Jackson 2021).

Biophysical constraints, however, can go beyond knowledge barriers and impose true limits on adaptation options—where a solution simply isn't possible. Under rapidly changing conditions, there may be no management interventions capable of achieving the persistence of an existing ecosystem or species *in situ,* requiring consideration of alternative conservation objectives and adaptation outcomes. In this context, biophysical knowledge is important to guide design and selection among compromises and trade-offs. Lack of knowledge about when such limits may be reached can delay investment in innovations designed to facilitate ecosystem adaptation and directed transformation, rather than attempting to preserve historical ecosystem conditions.

Gaps in biophysical knowledge can be especially significant in the early phases of the innovation lifecycle, including during problem exploration and definition and in the identification of potential adaptation options and management interventions.

Technical/management knowledge. Technical knowledge regarding how to manage species and ecosystem processes is similarly important, and gaps in such knowledge can constrain the development of new adaptation approaches. Most of our current understanding of management interventions, and responses of target resources, is based on experience under historical climatic conditions that may not have future analogs. Unfortunately, in the language of brokerage firm disclaimers: "Past performance is no guarantee of future success." Technical knowledge of potential management options can also be hindered by a lack of awareness of insights and experience that may exist among differing knowledge systems and communities of practice (e.g., Western science vs. Indigenous knowledge and practice).

Lack of technical knowledge and skills can also be a barrier for those involved in on-the-ground implementation of adaptation interventions. This includes lack of technical know-how or skills by land managers required to implement proven or promising interventions on-the-ground (e.g., Cappellesso and Thomé 2019, Diogenes et al. 2020), and by organizations implementing innovative planning or decision processes (del Río 2010, Banamwana et al. 2022). For example, Breed et al. (2019) note that restoration ecologists should be trained in the application of genomic technologies to fully capitalize on emerging opportunities. In some cases of highly technical interventions, a solution may be the establishment of service provider industries or organizations, such as to provide ecological or climate modeling services or genomic analyses (Breed et al. 2019).

Limits on technical/management knowledge can affect both early and later stages of the innovation lifecycle. Lack of knowledge of possible management techniques and interventions may constrain the identification of viable options during the ideation stage of the cycle, while barriers to the technical deployment of options can limit evaluation of feasibility and lessen the chance of a particular idea crossing the lifecycle's valley of death and being successfully implemented. That said, research, experimentation, and pilots during the innovation process can have a direct influence on overcoming those technical and feasibility constraints, as can the emergence of new technologies or changing economic or social conditions.

Human dimensions knowledge. Insufficient attention to the human dimensions of ecological problems, including their social, political, and economic context, can limit understanding of integrated natural/human systems and undermine the potential for innovations to move into implementation and broader diffusion. Effective development of innovative solutions is highly dependent on understanding community and stakeholder values. Insufficient attention to the values, concerns, and problem perceptions of stakeholders and rights-holders can lead to wasted investment in developing approaches that are not fully informed (and may be ineffective), do not gain acceptance for implementation, or are subject to substantial delays in implementation due to costly and time-consuming campaigns to increase acceptance. In particular, perceptions of risk and relative costs and benefits can differ greatly among sectors and stakeholders. An example outside of the climate adaptation space is the significant challenge encountered in many jurisdictions in efforts to introduce genetically modified food crops (Smyth 2020).

Knowledge of human dimensions, or lack thereof, affects the full range of the innovation lifecycle, starting with an understanding of the problem as seen through the values of various rights-holders and stakeholders. Perceptions of risk can help inform the screening and evaluation phase of the innovation process and provide an opportunity for additional work to better characterize and reduce risks to negligible, acceptable, or tolerable levels (Chapter 7). Finally, an understanding of how novel solutions can offer co-benefits across sectors or from different value perspectives can provide opportunities for gaining community allies in the implementation of novel adaptation approaches (see Section 6.2.2).

5.3.2. Resistance to New Ideas

Managing biodiversity in the face of a rapidly changing climate is forcing natural resource managers to rethink a number of existing practices and aspirations. Particularly challenging for many is a shift in paradigms: from managing for *persistence* of current conditions or restoration to historical states, to intentionally managing for *change*, including through actively directing ecological transformations (Hagerman and Satterfield 2014, Stein et al. 2014, Prober et al. 2019, Schuurman et al. 2022). As a result, resistance to new ideas is one of the most profound barriers to promoting innovative adaptation practices and outcomes. The challenge of accepting shifting paradigms is not unique to the biodiversity and natural resource management community, but rather is a long-standing narrative in the history of science. In their training and practice, scientists become heavily invested in particular ideas, concepts, theoretical frameworks, and assumptions that they rely on in pursuing their research. These assemblages of concepts, assumptions, and demonstrations form coherent platforms for further work, and scientists are resistant to abandonment or disruption of these frameworks, especially in the absence of something significantly better (Kuhn 1962, Kitcher 1993). The history of science is laden with examples of such resistance. For instance, accumulating evidence for the existence and action of reverse transcriptase (the key enzyme in such retroviruses as HIV, hepatitis B, and many cancer-causing viruses) met strong resistance for nearly a decade because it seemed to contradict the "central dogma" of molecular biology that genetic information flow is unidirectional from DNA to RNA to protein (Coffin and Fan 2016). Until the 1990s, most ecologists based their work on assumptions of environmental stasis or stationarity, resisting arguments and evidence that past, present, or future climatic change had much relevance for populations and communities.

In the realm of climate adaptation, resistance to new ideas and information is not simply a result of limited knowledge, but often can be a result of conflicts with underlying value systems, even among scientists and natural resource managers. As a result, the problem cannot just be viewed and addressed through a "knowledge deficit" frame or response (Gorddard et al. 2016). Indeed, continued public resistance to the reality of climate change itself (i.e., climate denial) is an example of how underlying values and ideologies can reject seemingly insurmountable amounts of scientific evidence. Resistance to acknowledging the reality and implications of climate change can complicate efforts to successfully implement novel adaptation approaches, particularly when their outcomes diverge from traditional conservation aspirations. For example, despite the growing climate-driven threats to western U.S. forests, there are small but vocal pockets of the environmental community that reject the notion that adaptation or active management approaches are needed in these forests.

Lack of public understanding about the scope and consequences of climate change can also complicate engagement with communities and stakeholders in adaptation planning processes, and limit their openness to embracing adaptation actions (whether novel or not). Even managers and communities that acknowledge climate change and its potential impacts can have a difficult time abandoning long-held goals that are based on science and values formulated under prior climatic conditions.

The resistance to new ideas can affect the entire innovation cycle, for instance through limiting the range of ideas identified in the early stages, or constraining which ideas are selected for further development and testing, or for consideration for piloting and implementation.

5.3.3. Evidence for Effectiveness

Evidence for the effectiveness of many current adaptation approaches is still limited (Hansen et al. 2023), and lack of evidence can be a barrier for moving innovations into practice. Because of the risk-averse nature of many agencies and decision-makers (Section 5.1.1), uncertainties regarding the efficacy of a given practice (whether novel or not) can inhibit their willingness to make needed investments and implement innovations. Repurposing of well-established practices for adaptation purposes, whether there is clear evidence for their efficacy or not, may be viewed as less risky than adopting novel approaches. Lack of evidence can be particularly limiting in cases where intervention options run counter to current management conventions or have potentially undesirable outcomes. In Australia, for example, there has been reticence to implement climate-adjusted seed provenancing strategies in restoration plantings, owing to uncertainty about effectiveness and potential risks (e.g., Prober et al. 2017). To overcome this barrier, a series of embedded experimental plantings has been established, which over time are expected to provide data on effectiveness for different species and environments. In contrast, the Province of British Columbia, Canada, has fully embraced such an approach and issued guidelines for climate-based seed transfer based on extensive provenance and adaptation trials, as well as a formal assessment of impacts, risks, and opportunities (O'Neill et al. 2017).

Lack of evidence is a greater issue during the middle and later phases of the innovation lifecycle because it is during those phases that organizational support and commitment is required to more fully develop and refine an idea and to move it toward broader implementation. Concerns of decision-makers might focus not just on evidence of effectiveness, but also whether an intervention is suitable for deployment in different regional, ecological, or social contexts.

5.3.4. Poor Knowledge Transfer

Inadequate knowledge sharing and transfer can also be a barrier to innovation. Knowledge management and sharing requires skills and investments, but is often undervalued within conservation organizations and agencies. Kernecker et al. (2021) highlight that "observability," or making the results of an innovation visible to others through peer observation and communication, is important for propelling its diffusion. Because the results of many natural resource management and adaptation projects are documented only in "gray literature," there is often a challenge in widely sharing the results of those experiences. Transferring experiences and knowledge from the gray literature into more discoverable peer-reviewed publications is a particularly significant challenge for knowledge sharing (Root-Bernstein and Ladle 2010, Prober et al. 2019). Knowledge sharing and open access to information is an area where there can be significant differences among institutions, particularly those in the nonprofit sectors versus the private sector. Many innovation hubs in the technology, aerospace, and other business spheres (e.g., skunkworks, innovation labs) operate in ways designed to protect intellectual property and proprietary business information. While competition and rivalries exists among nonprofit conservation organizations and among academic and agency researchers, there is a trend toward collaboration, with data and knowledge sharing becoming more routine, and increasingly a requirement of grant funding (Mearns 2012).

Knowledge transfer and sharing are relevant across the innovation cycle, from ideation, research and development, to implementation and wider adoption through planning and community consultation. Sharing of knowledge among those facing similar risks, and across diverse knowledge systems and sectors can be particularly helpful for yielding a range of new ideas during the early phases of the innovation lifecycle. Similarly, the development of novel adaptation solutions can benefit greatly from learning what others have tried and about their successes and failures.

5.4. Capacity Barriers

Limited capacity, including time, funding, and staffing, are widely identified as key barriers at every phase of the innovation lifecycle (del Río et al. 2010, Root-Bernstein and Ladle 2010, Schoenefeld et al. 2022). Capacity constraints in turn can be the cause of, or an amplifying factor in many of the other barriers described above. We explore three commonly described capacity constraints—time, money, and people—acknowledging that they are closely related and overlapping. For instance, money can alleviate time constraints and help address limitations on staffing and expertise.

- Lack of time
- Limited financial capacity
- Limited human capacity

5.4.1. Lack of Time

Time is one of the most limited commodities for natural resource professionals, who are often asked to do "more with less." As a result of such time pressures, the path of least resistance can be to rely on existing "tried and true" management approaches. Although new approaches may ultimately result in more efficient and effective management techniques, the development of novel approaches takes time. In particular, the innovation literature suggests that having flexible time is of particular importance for teams to carry out the exploration and experimentation needed to rethink a problem, identify novel solutions, and carry out the testing and refinement needed before deployment. For many working in biodiversity conservation and natural resource management, these activities fall outside explicit job duties, and there may be few organizational incentives for engaging in them (Section 5.1.3). Staff cannot innovate, regardless of organizational incentives, if they are not provided with the time to do so, including the time required to explore problems or reconsider technical or managerial processes (Murphy and Gouldson 2000, del Río et al. 2010, Root-Bernstein and Ladle 2010). Similarly, staff will be unlikely to adopt and deploy new innovations if there is inadequate time available to research and localize potential new approaches. Finally, engaging stakeholders and rights-holders in participatory planning processes takes time, both to build trust and to offer meaningful and authentic opportunities for input.

An additional time issue in the context of biodiversity adaptation is the temporal delay in seeing the effects of adaptation actions manifest themselves. Such response times often exceed the two- or three-year project period of most competitive funding cycles. The effects of many actions will have very long-term trajectories, which adds a further challenge to applying an adaptive management approach during the development and refinement of adaptation innovations.

5.4.2. Limited Financial Capacity

Funding is the lifeblood of conservation organizations and agencies, and how much funding is available, for what purposes, and over what timeframe has a direct effect on their capacity to invest in adaptation efforts generally and innovation specifically. Organizational resources tend to be allocated to existing programs, posing a challenge for the financing of new initiatives, regardless of the focus. This can be especially true for the development of innovations that may run counter to, or even pose a threat to, normal business practices.

Financial barriers to innovation, apart from its connection to the availability of relevant staff (Section 5.4.3), include the challenges of obtaining financial support for developing, testing, or deploying innovations (Björklund 2018, Diogenes et al. 2020, Crump et al. 2021, Harsanto et al. 2022) and of sustaining funding over periods that often exceed those of standard funding cycles (Crump et al. 2021, Fusco et al. 2020, Harsanto et al. 2022). The National Climate Resilience Framework emphasizes the need for more flexible and patient financial resources for climate resilience projects (CEQ 2023). Such projects often suffer from underinvestment, the Framework notes, due to factors like long and/or uncertain payback periods, benefits that accrue to a community rather than solely to investors, and traditional accounting mechanisms that tend to focus on direct financial benefits while limiting consideration of many indirect benefits such as water quality improvements (CEQ 2023).

5.4.3. Limited Human Capacity

Tackling adaptation challenges in new and novel ways requires someone to do the work. This not only includes adequate numbers of people, but those with relevant and appropriate disciplinary expertise, which may be outside the skill sets of existing staff (or skills that no one has yet). This includes sufficient research capacity, whether on staff or through partnerships, capable of evaluating and testing the efficacy of adaptation innovations that might be proposed. Limitations on human capacity can be exacerbated by other institutional and social barriers, including a tendency to operate in silos (Section 5.2.1) and challenges some organizations or agencies have in forming collaborative partnerships. Even when suitable expertise exists in an organization, a lack of institutional incentives can discourage staff from engaging in experimentation and innovation (Murphy and Gouldson 2000). Dedicated innovation teams can also be easy targets for budget cutbacks and staff reductions (Sandberg and Aarikka-Stenroos 2014). Limited human capacity can also contribute to knowledge and learning barriers (Section 5.3), and perpetuate or exacerbate financial constraints (such as when staff are not available for grant writing or fundraising, or these responsibilities unduly compete with programmatic work).

Lack of adequate human capacity and relevant expertise, whether among organizational staff or in partnerships, can constrain or impede all aspects of the innovation lifecycle. Although this may be obvious for early phases in the cycle, during which teams are involved in concept development, refinement, and testing, it also applies as innovations move toward implementation and deployment at scale. Capacity for diffusion and deployment can be needed to promote horizontal diffusion of innovations across an organization or among partners (i.e., across similar units such as parks or refuges) as well as vertical diffusion of innovations up and down organizational hierarchies (Schoenefeld et al. 2022).

Engaging diverse rights-holders and stakeholders can offer new insights into climate-related problems and lead to the development of novel adaptation solutions. Photo: Elders from Kwethluk, Alaska, at a Permafrost Pathways workshop in 2023. Credit: Greg Fiske/Woodwell Climate Research Center.

Chapter 6. Enabling Conditions for Innovation

Given all the barriers described in the previous chapter, it may seem a wonder that innovation ever happens! Clearly, that is not the case, and the purpose of enumerating those barriers was not to deter individuals and agencies from striving to be more creative and innovative, but rather to help chart a path forward to overcome them. This chapter focuses on the flip side of this issue by specifically considering the conditions that enable, rather than inhibit, creativity and innovation.

Creativity is often viewed as an individual trait with innovation the result of individual or team actions as they are either enabled or constrained in an institutional context (Amabile 1988). In reviewing best practices of highly innovative organizations, NASEM (2016) emphasized the importance of considering an organization's overall "innovation ecosystem," which they characterized as including: leadership and organization; tools and processes; and people and culture. In particular, they noted that all such organizations "had cultures that celebrated innovation and accepted that part of innovation was taking risks and tolerating failures along the way to ultimate success" (NASEM 2016).

We focus here on describing factors or "enabling conditions" for fostering creativity among staff and innovation within an agency or organization. Building on and responding to the barriers detailed in Chapter 5, we identified the following four general categories and a dozen enabling conditions for promoting innovation:

Institutional Culture

- Committed leaders and culture of trust
- Nimble and adaptive
- Open to taking risks
- Outcome focused

Box 6.1. Enabling conditions for innovation.

Institutional Culture

Committed Leaders and Culture of Trust—Committed leadership that supports independent thinking and creative approaches; trust among institutional leaders and staff, and across teams.

Nimble and Adaptive—Processes for continuous learning and adjustment (not just following established rules, traditional tactics, and existing goals); ready and responsive to surprises.

Open to Taking Risks—Overcome inherent aversion to taking risks; procedures to assess risk (including the risk of inaction) but still incentivize innovation and encourage acceptable levels of risk-taking.

Outcome Focused—Focus on achieving outcomes rather than simply adhering to business-as-usual actions and approaches; willingness to articulate and adopt future-oriented, rather than retrospective, goals and outcomes.

Governance and Decision-making

Participation of Rights-holders and Stakeholders—Processes in place for meaningful participation of a diverse range of interested and affected groups—including in problem identification.

Transparency in Trade-offs—Processes for exploring potential outcomes of novel adaptation approaches in ways that allow for an understanding of costs, benefits, and consequences from the perspective of different values and rights-holders/stakeholders.

Knowledge and Learning

Novel Insights—Invests in generating new information and deeper understanding that can lead to novel insights into the nature of the problem and into pathways capable of addressing adaptation challenges.

Diverse Perspectives—Processes that consider diverse perspectives and varied forms of knowledge (e.g., Western science and Indigenous knowledges) and encourage cross-disciplinary thinking that supports, rewards, and encourages knowledge co-creation.

Continuous Learning—Processes for effective learning and knowledge management to support shared learning and knowledge exchange within and across institutions and networks.

Commitment to Evidence Gathering—Mechanisms and support for relevant and effective monitoring and evaluation, including processes for determining what needs to be monitored, how, by what metrics, and by whom.

Organizational Capacity

Sufficient Resources—Sufficient time to allow for exploration, ideation, and experimentation and avoid the pressure to deploy only the most expeditious, business-as-usual approaches; sufficient funding and material resources to support the creative work of staff and partners, including those historically excluded from such processes.

Appropriate Expertise—Availability of both specialized expertise as well as staff and partners with varied perspectives, knowledge systems, and expertise; process to support recruitment, retention, and support of diverse leadership, staff, and partners.

Governance and Decision-making
- Participation of rights-holders and stakeholders
- Transparency in trade-offs

Knowledge and Learning
- Novel insights
- Diverse perspectives
- Continuous learning
- Commitment to evidence gathering

Organizational Capacity
- Sufficient resources
- Appropriate expertise

We identified these categories, and the enabling conditions for each, based on a review of relevant literature, an exploration of the topic among workgroup members, and participant input from a 2022 National Adaptation Forum workshop. For each enabling condition, we offer a brief discussion about how and why it can be important in creating a conducive environment for innovation. We also offer a set of "diagnostic questions" for each that are designed to help individuals or groups probe their own context so they can work toward advancing cultures, processes, tools, and practices that are conducive to promote innovation within the organization. Honest reflection on these questions can serve as a basis for engaging with institutional leaders and staff to explore what specific policies and practices might serve to enable an innovation culture at the institutional level and inspire an innovation mindset at the level of individuals (Chapter 9). Appendix A offers a consolidated list of these enabling conditions and associated diagnostic questions.

Adaptation practitioners, regardless of their position or role in an organization, can adopt many of the suggested practices and approaches. Some practices, however, may involve financial, strategic, or structural decisions that require buy-in and commitment from organizational leadership or external partners including rights-holders and stakeholders. Nonetheless, becoming a more innovative organization is a journey, and one that depends on and benefits from both bottom-up and top-down awareness, engagement, and commitment.

6.1. Institutional Culture

As described in Chapter 5, a number of barriers to innovation are associated with institutional traits, including an unsupportive culture and leadership, a lack of incentives, and perhaps most importantly an aversion to taking risks. Consequently, several important enablers for innovation relate to the broad category of institutional culture. Creating an institutional culture that encourages, rather than discourages, innovation depends on internal factors that are largely within an institution's control. Changing entrenched institutional norms and policies, of course, is neither easy nor without challenges, which is why supportive leadership and processes for engaging diverse perspectives is so essential to this process. To help overcome this suite of institutional barriers, we identify and explore the following four enabling conditions:

- Committed leaders and culture of trust
- Nimble and adaptive
- Open to taking risks
- Outcome focused

6.1.1. Committed Leaders and Culture of Trust

Committed leadership that supports independent thinking and creative approaches; trust among institutional leaders and staff, and across teams.

Barriers addressed: unsupportive institutional culture; lack of incentives; restrictive regulations and policies.

Committed and supportive leadership represents one of the most important enablers of innovative adaptation practices. Leadership not only can set the tone for innovation by embracing a forward-looking organizational vision and strategic posture, but can cultivate a culture of trust that empowers staff to think creatively, take risks, and engage in experimentation without fear of failure. Indeed, supportive leaders and a culture of trust is foundational to realizing many of the other enabling conditions described below.

In the context of adaptation, leaders exist at all levels within organizations, from CEOs and agency heads through the ranks of department heads and team leads. As noted in Section 4.4.3, innovation can emerge from both top-down and bottom-up approaches, and committed leaders are critical to both. Top-down approaches depend on a strong vision from senior leaders and the ability to align institutional focus, structure, and resources around advancing that vision. Given the highly local and context-specific nature of climate impacts on natural systems and landscapes, however, biodiversity adaptation will often rely on the insights and creativity of those closest field-level management. Leadership qualities that facilitate bottom-up innovation include being both an advocate for and challenger of new ideas, encouraging teams to collaborate and experiment, and giving them the freedom to fail and to learn from those failures (Deschamps 2017). Blackwater National Wildlife Refuge (Section 8.1) is an example of supportive leadership enabling such bottom-up innovation. In that instance, the refuge manager challenged staff to shift perceptions of the refuge from being emblematic of climate-related losses (from sea-level-rise impacts to marsh habitat) to an illustration of how proactive adaptation responses could influence the trajectory of ecological changes and help sustain fish and wildlife resources.

A culture of trust is critical for enabling individuals and teams to try new initiatives and take the risks necessary to achieve innovative adaptation. Trust, however, is relational and operates at different scales—an individual leader may enjoy the trust of her colleagues, but those same colleagues may not trust the overarching organization. If there is a history in an organization of leaders not supporting employees, or changing mandates and priorities with little warning or consultation, trust may need to be established or rebuilt. The challenging reality, and a central maxim in the trust literature, is that trust takes a long time to establish, but can be eroded very quickly. Known strategies for fostering and maintaining trust over time at multiple scales include: the importance of follow-through and keeping commitments; perceptions of competence; perceptions of concern and care; a track record of supporting people; meaningful consultation and inclusion of ideas; procedures that are viewed as legitimate; honest communication; and transparent decision-making.

Diagnostic Questions

Committed Leaders/Culture of Trust

- Do institutional leaders at various levels understand the imperative for adaptation and innovation? Is a commitment to innovation embodied in the organization's vision, processes, and/or resource allocations?
- Assuming a commitment to innovation, does the institution take a top-down or bottom-up approach to innovation, or some combination of the two?
- Do institutional leaders foster and support creative thinking and approaches? Do individuals and teams feel empowered to experiment and try new things, and trust that supervisors give them the freedom to learn from failure?
- Is there a high level of trust in institutional leaders, and among and across teams, or are there steps needed to build/rebuild trust?

6.1.2. Nimble and Adaptive

Processes for continuous learning and adjustment (not just following established rules, traditional tactics, and existing goals); ready and responsive to surprises.

Barriers addressed: resistance to new ideas; unsupportive institutional culture; lack of incentives; poor knowledge transfer; lack of time.

Innovation is most effectively fostered in organizations that have a nimble and adaptive culture. By definition, innovation involves doing things in a new way, which usually requires modifying, deemphasizing, or abandoning some of the old ways. This entails both an internal ability to change how things are done, and responsiveness to changing external circumstances and opportunities. Just as a nimble individual climbing a steep and rocky slope must continually engage different muscles and muscle combinations to adapt to changes in footing, slope, and wind, a nimble organization must be able to adjust its staff and resource commitments to adapt to changing environmental, technological, and societal contexts.

A key feature of nimbleness is responsiveness to changing circumstances. Even in the absence of obvious alternatives to current approaches, a nimble organization will need to identify the real or potential limitations and deficiencies of those current approaches. Identification of what's working effectively, what's working well but falling short of potential needs, and what's likely to break down or become obsolete, is important in identifying possible innovations, and in making smart decisions about reallocation of effort when innovation opportunities arise. Anticipating which currently successful practices or approaches are likely to lose efficacy under environmental (or societal) change can foster recognition and development of innovative alternatives that can replace older practices before they begin to fail.

Responding in an adaptive way to changing environments and emerging opportunities is fostered by *organizational awareness,* which includes both *self-awareness* and *situational awareness*. In a self-aware organization, leaders and staff at all levels have a clear understanding of how the organization works, how resource allocation priorities and decisions are made, and what the organization's respective strengths and weaknesses are. Situational awareness has multiple dimensions, but among the most important are understanding the ways in which environmental change is likely to affect the resources under its management or protection, and the constraints and opportunities imposed by its societal context (rights-holders/stakeholders, governing bodies, constituencies, funding sources, etc.). These two elements of organizational awareness can put an organization in a good position to be both nimble (in context of its mission and constraints, both internal and external) and adaptive.

Adaptive capacity is a core concept in climate adaptation, and can be defined as "the ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences" (IPCC 2022). In conservation and natural resource management, adaptive capacity is often considered in the context of assessing the climate vulnerability of species and ecosystems (e.g., Thurman et al. 2020).[7] However, as the above definition implies, adaptive capacity is a quality of institutions as well. Indeed, having the capacity to adjust and respond to changing conditions is an important enabler of innovation generally and adaptation specifically. For example, Armsworth et al. (2015) explore whether agencies and major conservation organizations have sufficient flexibility to respond to changing conditions and needs by reallocating funding, staff, or other resources, concluding that organizational change may be a prerequisite for any major rethinking of conservation actions.

Timing can be critical in successful innovation, and effectiveness adaptation can depend on deployment "when the time is right." Appropriate timing can be contingent on environmental, ecological, and/or societal processes. An innovative intervention to nudge an ecosystem in a desired direction may be successful only when employed during an unusually wet year after several years of drought. A new approach to managing a population or ecosystem may be most effective in the aftermath of a particular type of event (e.g., a moderate disturbance, a recruitment burst or sudden decline of a particular species population). A new initiative may receive sufficient financial or stakeholder support only after a societal change—for instance, a judicial decision, a change in political leadership, a newsworthy event. This has given rise to the adage "never let a crisis go to waste." A nimble and adaptive organization should be prepared to move quickly when opportunities arise, and in some cases may need to delay full deployment of an innovation until the time is right.

[7] Assessing climate vulnerability typically involves a consideration of exposure, sensitivity, and adaptive capacity (Glick et al. 2011, Dawson et al. 2011, Foden et al. 2019, Thurman et al. 2020).

> **Diagnostic Questions**
>
> **Nimble and Adaptive**
>
> - Are staff at various levels empowered to adjust program and project design and delivery based on changing conditions or on emerging evidence of project success, underperformance, or failure?
> - Does the institution have formal mechanisms or incentives in place for encouraging adaptive behaviors?
> - Does the institution have flexibility in the allocation of internal assets (personnel, financial, material) to support promising initiatives and novel work?
> - Does the institution have a culture of partnership and collaboration that can allow it to be nimble in addressing changing needs and taking advantage of emerging opportunities?

6.1.3. Open to Taking Risks

Overcome inherent aversion to taking risks; procedures to assess risk (including the risk of inaction) but still incentivize innovation and encourage acceptable levels of risk-taking.

Barriers addressed: risk aversion; lack of incentives; resistance to new ideas.

As highlighted in Chapter 5, aversion to taking risks is one of the most significant barriers to innovation, and this is especially true for conservation practitioners and organizations. Conversely an institutional culture that is open to taking risks is widely viewed as key to enabling innovative thinking and action. Because a reluctance to take risks can be a function of both individual behavior and temperament as well as institutional culture and business practices, encouragement to take responsible levels of risk must operate at both scales.

Creating a safe and trusting work environment (see Section 6.1.1) can be especially important for promoting outside-the-box thinking without fear of reputational risk or organizational censure. This is closely tied with promoting an institutional culture that rewards experimentation and learning from failure, rather than penalizes any and all types of failures or project shortcomings. Beyond limiting the potential negative repercussions from risk-taking, there are a variety of incentives that can be instituted that actually reward innovative thinking and risk-taking. These incentives can come from within an organization (e.g., employee recognition programs, bonuses, etc.) or from outside, for instance through the availability of external grant programs, awards, or even prizes (e.g., "grand challenges"). Public and private funding agencies also have an important role to play in allowing conservation and natural resource management agencies to become more comfortable in taking risks. Although funders often acknowledge the importance of risk-taking and learning from failure, in most instances there are still powerful incentives and expectations for grant recipients to report only on successes. As a result, there is an opportunity for government funders and philanthropic donors to encourage more responsible risk-taking as part of grant applications and in how grant recipients are evaluated and considered for future funding opportunities.

Organizations and agencies have different risk tolerance profiles, and government agencies are typically very risk averse, with policies and procedures that tend to disincentivize rather than promote risk-taking. Partnering with private sector or nonprofit organizations can be an important strategy for experimentation and risk-taking that would otherwise be difficult for public agencies to carry out on their own. Wade Crowfoot, Secretary of California's Natural Resources Agency, has noted, "Elected leaders or appointed leaders are not known for risk taking. Some of us can sometimes, but it's really [partners] that bring the creative ideas with the big ambitious solutions...and then people like me can help support that vision."

Foundational to encouraging responsible risk-taking is having in place organizational procedures, practices, and expectations for risk assessment, management, and communications (see Chapter 7). Such risk management protocols allow researchers and practitioners to consider the implications of new ideas and concepts with respect to critical uncertainties and possible outcomes (both favorable and adverse; intended and unintended). It also offers a framework for weighing the possible risks of taking a particular action against the possible risks of inaction—something that is often underrepresented or omitted from applications of the precautionary principle alone.

Diagnostic Questions

Open to Taking Risks

- Does the institution have business practices or cultural norms that offer incentives for individuals or teams to take risks, track results, and learn from both successes and failures?
- Does the institution have effective risk assessment and management practices designed to avoid activities that carry unacceptable or intolerable risks, but not stifle the development of novel practices with acceptable risk profiles?

6.1.4. Outcome Focused

Focus on achieving outcomes rather than simply adhering to business-as-usual actions and approaches; willingness to articulate and adopt future-oriented, rather than retrospective, goals and outcomes.

Barriers addressed: unsupportive institutional culture; lack of incentives; lack of evidence.

Focusing on desired conservation outcomes can be important for opening up new and more effective approaches to adaptation. Although this may sound fundamental, many agencies and organizations are deeply invested in particular traditions, often based on historical experience and legacies, which are bolstered by institutional culture, policies, and patterns of resource allocation. As a result, there are often powerful incentives to continue carrying out business-as-usual actions and approaches, even in the face of significant external (environmental and social) changes.

A useful framework for project management and evaluation distinguishes among project inputs, activities, outputs, and outcomes, with outcomes representing the desired impact of the effort (Margoluis et al. 2013). For many reasons, natural resource managers generally focus on activities and outputs, with related monitoring emphasizing measures of process and product rather than ultimate impact. Institutions in many sectors are adopting planning processes that involve the development of a *theory of change,* which starts with an articulation of the desired end point or outcomes. Through development of a "results chain," those outcomes can then be used to link needed inputs, activities, and outputs.

An outcome focus is a key enabler of adaptation innovation for two principal reasons. First, in the face of rapidly changing conditions, conservation goals—and therefore desired outcomes—may need to evolve. Indeed, "reconsider goals, not just strategies" is one of the core principles of climate-smart conservation (Stein et al. 2014). Unless planners and managers explicitly reevaluate their goals in light of changing conditions, institutions run the danger of carrying out activities and achieving outputs that are out of sync with climate trends and adaptation needs. Second, there are many forces in play that constrain the types of management activities that an institution and its staff actually carry out. Institutional culture and processes can be a powerful reinforcer of a "this is the way we've always done it" attitude. Successful innovators are always looking at whether there may be a more efficient or effective way to get things done (and achieve key outcomes), and this is especially important in light of shifting conditions and adaptation goals.

Focusing on outcomes can also help refine or redefine the nature of the problem being addressed, which is foundational to the first phase of the innovation lifecycle. In that way, it can both open up new approaches to more effectively achieving existing goals, as well as stimulate novel solutions to address forward-looking and climate-informed conservation goals and outcomes.

Diagnostic Questions

Outcome Focused

- Are existing institutional goals likely to remain robust in the face of projected climate change or will modifications or refinements be needed to make them more climate-informed?
- Do existing institutional metrics and reward structures encourage carrying out business-as-usual actions and approaches, or allow for rethinking actions and strategies to better achieve desired adaptation outcomes and impacts?
- Can the institution describe a "theory of change" for its adaptation work, including a clear articulation of the desired outcomes or impacts of those efforts?

6.2. Governance and Decision-making

Governance and decision-making processes underpin as well as bound the ability of organizations and agencies to carry out their work and play a key role in encouraging or discouraging innovation. As noted in Chapter 5, barriers to innovation and adaptation in the realm of governance and decision-making can include overly restrictive laws, policies, and regulations (or a perception of those constraints); inconsistent or conflicting values among resource managers, stakeholders, and other rights-holders; and a lack of engagement with key rights-holders and stakeholders, including historically marginalized groups, that can be exacerbated by unhealthy power dynamics. From our collective research and practical experiences, as well as the extensive literature on this topic, we highlight the particular importance to promoting innovation of: 1) ensuring that processes are in place to meaningfully and equitably include the participation of diverse communities and groups; and 2) to ensure that processes are in place to identify and deliberate among trade-offs, including those that are values-based, in considering innovation options and alternatives.

Consequently, we identify and elaborate on two enabling conditions:

- Participation of rights-holders and stakeholders
- Transparency in trade-offs

6.2.1. Participation of Rights-holders and Stakeholders

Processes in place for meaningful participation of a diverse range of interested and affected groups—including in problem identification.

Barriers addressed: Lack of diversity; operating in silos; power dynamics.

The participation of diverse rights-holders and stakeholders is crucial for enabling effective and just adaptation, and this also applies to the development and implementation of new or novel adaptation approaches. Conservation and adaptation initiatives can and have had significant impacts and implications on local communities, including Indigenous populations, communities of color, economically distressed populations, and other marginalized and underserved groups. Moreover, it is widely acknowledged that these groups hold important perspectives and knowledge critical to effective conservation and adaptation, but that these perspectives have often been excluded from decision-making processes. At the international level, the participation of Indigenous groups in environmental management, decision-making, and governance is secured by the U.N. Declaration on the Rights of Indigenous Peoples and reinforced by the U.N. Convention on Biological Diversity. Of particular importance is the right of Indigenous peoples to self-determination and the associated principle of "free, prior, and informed consent" (FPIC). FPIC is characterized as a set of rights that enable decision making, realized free from coercion, within a community's own cultural framework, and with adequate time to review and assess all information necessary to make an informed judgement on the long-term risks and benefits of proposals (Mitchell et al. 2019).

Despite these declarations and intentions, achieving meaningful engagement and participation by Indigenous and other local communities is still a challenge and learning process for many conservation organizations and natural resource management agencies. Nonetheless, a number of NGOs are beginning to put these values into practice and in recent years the U.S. government has been implementing policies and practices that are starting to better address Indigenous engagement in planning and decision processes. What is clear are some key principles and areas to consider in support of meaningful and respectful engagement moving forward. One consideration is the level of inclusion that Indigenous peoples and local communities have in a given decision-making context. Historically, and despite claims to the importance of diverse perspectives, Indigenous and other marginalized voices have often been excluded when it comes to problem framing and decisions, leading to criticisms that many engagement processes remain inadequate at best, and tokenistic, or even harmful, at worst. This can often be traced back to a governance process (e.g., regarding roles) that is relatively undefined, and that then becomes interpreted vaguely, typically resulting in limits to the ways that different groups are able to contribute. A second topic concerns the issue of capacity, with Tribal representatives and other affected community members often asked to volunteer their time and expertise to meaningfully engage in conservation and adaptation decision-making processes to which they may be invited. This can pose a systemic barrier to meaningful participation and engagement. The central message is that diverse representation in adaptation innovation discussions is key, but insufficient—it is also crucial to establish and maintain meaningful processes for input.

Innovation can also be sparked and enabled by the inclusion of more diverse perspectives and different forms of knowledge (see also Section 6.3.2). Such diverse perspectives can include Indigenous knowledge systems (often referred to as "traditional ecological knowledge") as well as the on-the-ground experience and understanding gained by long-time landowners, land managers, hunters, and anglers. Such knowledge, when appropriately and respectfully engaged, can be particularly important in the problem definition state of the innovation lifecycle, since these insights may reveal entirely new ways of perceiving the problem, and therefore open up new pathways for adaptation solutions. The involvement of rights-holders and stakeholders is also critical to establishing inclusive support for new approaches, which can be crucial for traversing the valley of death in the innovation lifecycle. The challenge in this moment is to reflect on the barriers that exist in current planning and decision-making processes and to act intentionally, and in collaboration with key partners to design and develop governance processes that can better enable the involvement of diverse perspectives and forms of knowledge in an equitable and just way.

Diagnostic Questions

Participation of Rights-holders/Stakeholders

- What is the role and level of involvement of Indigenous rights-holders and community stakeholders in adaptation decisions? Are the principles of free, prior, and informed consent being applied and are there opportunities for Indigenous and community leaders to meaningfully engage in framing of problems and crafting of possible solutions?
- Recognizing that one-size-fits-all approaches rarely work in local social-ecological contexts, is the role/process for involving rights-holders and stakeholders specifically defined?
- Are there opportunities to recognize and support the participation of rights-holders and stakeholders in the adaptation (and innovation) process (e.g., compensating for time, travel, etc.).

6.2.2. Transparency in Trade-offs

Processes for exploring potential outcomes of novel adaptation approaches in ways that allow for an understanding of costs, benefits, and consequences from the perspective of different values and rights-holders/stakeholders.

Barriers addressed: conflicting values; resistance to new ideas; operating in silos.

One thing we know about natural resource management—in fact, most things in life—is that you can't have it all. Adaptation often requires new or newly stated management objectives because implied or historical objectives, such as maintenance of historical conditions, may no longer be climatically or ecologically feasible (Harris et al. 2006, Williams and Jackson 2007, Hobbs et al. 2009, Jackson and Hobbs 2009). And when you choose one management technique such as prescribed fire or selective thinning, that action might preclude other possible actions such as wilderness designations. This preemption or exclusion of alternative approaches can arise from biophysical trade-offs, limits on time, labor, and money, and noncompatibility of management strategies and land uses.

But assumptions about these trade-offs, particularly when those assumptions are hidden from view and critical evaluation, or evaluated through limited perspectives, can hinder innovation in adaptation practice—both in the discovery and implementation of adaptation strategies. Clarity in the processes used to evaluate adaptation alternatives and increases in diversity of perspectives conducting that evaluation can shine new light on trade-offs and thereby increase the conditions conducive for adaptation innovation.

Adaptation innovation requires an ability to see across the entire adaptation solution space and seek out strategies that might be hidden from view or dismissed by traditional criteria or evaluation procedures. Identifying trade-offs can point toward or away from particular adaptation solutions, but sometimes those trade-offs can be overcome or transcended with innovative thinking. The recently developed RAD (resist-accept-direct) framework for adaptation planning, for example, offers a means for planners and managers to explore the trade-offs that could result from pursuing one trajectory of change over another (Thompson et al. 2020, Lynch et al. 2021, Schuurman et al. 2022). Although these three adaptation approaches can overlap both temporally and spatially in a given landscape (for instance, managing for persistence of ecosystem structure but transformation at the level of species composition), the framework provides a means for planners to consider a range of possible options and outcomes, and their resulting trade-offs, before choosing a preferred alternative. Exploring the implications of alternative futures and approaches depends on a variety of factors, including the criteria used to characterize and evaluate trade-offs, the scale of analysis, the potential for successful implementation, and the values of stakeholders involved in evaluation (Gorddard et al. 2016, Clifford et al. 2022).

To probe and choose among trade-offs requires an understanding of where they exist. Evaluating trade-offs can be as simple as developing a matrix of actions against evaluative criteria, identifying cases of exclusivity versus overlap and looking for cases that maximize the benefit-to-cost ratio (e.g., Richardson et al. 2009, Kwakkel et al. 2016). One way of growing the set of viable adaptation strategies, however, is being open minded, creative, and clear about the criteria used to evaluate trade-offs (i.e., the elements in an evaluation matrix). Both cultural and material measures and values should be included when evaluating side effects and co-benefits.

Another way to enhance innovation through clarifying trade-offs is to include a wide range of rights-holders and stakeholders with different values and management goals in the evaluation process (see Section 6.2.1, above). All management objectives involve costs and benefits borne, often unequally, by particular people and constituencies (Mutz et al. 2001). Managers, rights-holders, and stakeholders may evaluate alternative adaptation strategies and their trade-offs differently from another with different values and value systems (e.g., number of dollars and equity in decision-making and outcomes).

Natural resource management has often been contentious (Nie 2003), and adaptation introduces new dimensions and uncertainty to management decisions. In a democracy where many natural resources are publicly owned, transparency in trade-offs promotes equitable participation or representation in decision-making and enhances the social acceptability of those decisions (Parkins and Mitchell 2005). If decision-making authority is not already clear, such as established by statute or law, clarity about who has the authority to decide is also an important part of transparency (Butler and Schultz 2019). Without transparency in trade-offs, it isn't possible for parties affected by a management decision to advocate for their needs and perspective. If these groups have conflicting points of view, transparent trade-offs can encourage innovation as a means of uncovering novel "win-win" solutions. That said, in an era of rapid transformation, there will be many instances in which solutions that satisfy all parties simply cannot be found. Rather than finding such optimal solutions, decision-makers may need to be open to solutions that meet some level of acceptability or tolerability across stakeholders, an approach that is sometimes referred to as "satisficing" (Artinger et al. 2022).

Diagnostic Questions

Transparency in Trade-offs

- Is there a clear process in place to explore and confront possible trade-offs among innovations, and clear criteria for evaluating potential innovations and alternative strategies?
- Are all relevant parties, including rights-holders and stakeholders, participants in the process of characterizing and evaluating trade-offs from the perspective of shared as well as divergent values?
- Are novel adaptation approaches available that might overcome historical trade-offs and conflicts and create new opportunities for win-win solutions?

6.3. Knowledge and Learning

Effective biodiversity conservation and adaptation are dependent on a robust understanding of natural systems, the stressors and threats affecting species and ecosystems, and the efficacy of proposed and implemented adaptation strategies and management actions. It also depends on the context within which decisions are being made, including the values held by both decision-makers and stakeholders (Gorddard et al. 2016). From a review of the literature, together with our collective research and practical experiences, we identified four knowledge and learning-related conditions that are particularly important for promoting innovation and achieving adaptation outcomes:

- Novel insights
- Diverse perspectives
- Continuous learning
- Commitment to evidence gathering

6.3.1. Novel Insights

Invests in generating new information and deeper understanding that can lead to novel insights into the nature of the problem and into pathways capable of addressing adaptation challenges.

Barriers addressed: limited knowledge; lack of evidence; poor knowledge transfer.

New knowledge and novel insights have an especially important role in powering innovative approaches to addressing climate adaptation challenges. Scientific inquiry and discovery have always been central to conservation efforts, leading to continuously improved understanding of the condition of ecological systems, the stressors affecting the systems, as well as management responses for ameliorating those threats and restoring system function and health.

Clearly understanding and articulating the nature of the problem at hand is the starting point for innovation as well as adaptation planning, and more generally problem definition is foundational to structured decision-making approaches in natural resource management (Runge et al. 2020). New knowledge and novel insights into the scope and nature of the problem play an outsized role in revealing new opportunities for crafting solutions to the problem. In the context of adaptation, such problem statements must consider both current and future threats, taking into account near- and longer-term climate-related risks.

The types of new information and knowledge likely to contribute to innovative adaptation solutions are broad, ranging from information about biological resources and ecological processes, to changing climatic conditions, as well as the social, political, and/or economic factors. There is also a tight link between the emergence and use of new and innovative technologies and scientific tools, and the novel insights that those tools generate into the distribution, condition, and function of natural systems (Iacona et al. 2019). Examples of such tools include advances in remote sensing, imaging, and mapping technologies, microsensors, environmental DNA (i.e., eDNA), and artificial intelligence. Technological innovations in the study of species and ecosystems can be a powerful enabler of innovation in adaptation responses.

Climate change vulnerability assessments are a class of analyses that can reveal new insights into the potential impacts of changing climatic conditions on species, ecosystems, and communities. Such vulnerability assessments not only can help identify which species and ecosystems may be most vulnerable, but perhaps more importantly why they are vulnerable. Understanding the likely mechanisms of such vulnerabilities and risks serves as the basis for generating sets of possible adaptation options. Identifying a broad suite of possible adaptation options (Step 4 in the climate-smart conservation cycle) represents one of the most important steps in the adaptation planning process for innovation.

Novel insights are also more likely to come when people with diverse perspectives are meaningfully engaged in the process, including those from different scientific disciplines, communities of practice, and lived experience. Indeed, knowledge co-production, a process that involves both creators and users of information in knowledge generation, is an especially effective approach for generating novel insights in climate adaptation (Meadow et al. 2015, Enquist et al. 2017, Bamzai-Dodson et al. 2021, Rosemartin et al. 2023). For these reasons the enabling condition of *Diverse Perspectives* (Section 6.3.2) is key to generating novel insights into the nature of the problem and possible solutions.

Diagnostic Questions

Novel Insights

- What processes and investments are in place that can allow for the generation of new knowledge that might enable new perspectives on understanding the problem at hand?
- Is the institution making investments or engaged in collaborations designed to advance fundamental understanding of the system of interest and generate novel insights into the nature of the problem and possible adaptation responses?
- How are new and emerging technologies being adopted and deployed to generate new knowledge and insights into system condition and function and climate-related risks?

6.3.2. Diverse Perspectives

Processes that consider diverse perspectives and varied forms of knowledge (e.g., Western science and Indigenous knowledges) and encourage cross-disciplinary thinking that supports, rewards, and encourages knowledge co-creation.

Barriers addressed: operating in silos; lack of diversity; power dynamics; conflicting values; poor knowledge transfer.

The conservation and management of complex social-ecological systems in an era of escalating and extreme climate impacts poses profound challenges for adaptation innovation at all scales. Diverse perspectives provide the divergent ideas that are foundational to the innovation process, and as described in Section 5.2.2, a lack of diversity can hinder the development of successful and equitable adaptation solutions (Morrison and Steltzer 2021, Wailoo et al. 2023).

Diagnostic Questions

Diverse Perspectives

- Does the institution have leadership representative of diverse perspectives and backgrounds (culturally, socioeconomically, etc.) to guide the engagement of diverse rights-holders and stakeholders?
- Does the institution have processes in place, either internally or through collaborative partnerships, to access cross-disciplinary, multi-perspective thinking, and for considering and incorporating diverse forms of knowledge and worldviews, including from traditions other than Western science?
- Are diverse forms of knowledge and knowledge systems evaluated within the appropriate rules and standards of validation and verification of its production? Is there a process to support the autonomy and data sovereignty of diverse knowledge systems?

Scientific and other forms of knowledge (e.g., local, Indigenous) are critical to developing innovative responses to adaptation challenges. However, without reflecting on and working to overcome deep-rooted assumptions about science (or more broadly, knowledge), even the most well-intentioned efforts can fall short of being innovative, let alone effective. To begin with, all scientific knowledge is contingent. Whether an experimental field trial, climate, ecological or economic model, public survey, policy analysis, or ethnographic analysis (to name just a few forms of scientific knowing across the natural and social sciences), different disciplines offer critical, but partial understandings of complex systems and their functioning. Achieving innovative adaptation will require recognition, appreciation, and the incorporation of insights generated across diverse disciplines as the integration of those perspectives can lead to new models for understanding complex, socio-ecological systems. How we understand adaptation challenges to begin with is inescapably linked with the solutions that ultimately are crafted and implemented.

The inclusion of the word appreciation above is intentional and connects with the reference to those deep-rooted assumptions. In our own research and practice, it is not uncommon to encounter assumptions about “objectivity,” and more specifically that some scientific approaches have it, and others do not. But the concept of objectivity is a slippery and problematic one. All epistemologies and disciplines contain different rules of production and validation of evidence, and none are immune to value judgments. We need diverse forms of scientific knowledge to fully understand a problem to begin with, as well as an appreciation of the (sometimes divergent) values that are at stake in the development of solutions that draw on that knowledge in response to the problem (see also Section 6.2.1). In addition to embracing diverse disciplinary expertise, it is equally crucial to engage and consider local, traditional, and place-based knowledge (within appropriate protocols). Place-based knowledge generated from close observation and engagement with the natural world, and diverse ways of knowing are as crucial to this endeavor as climate change projections and ecological data.

For the reasons outlined above, it is practically a universal maxim today (and has been an aspirational principle for decades) to say that there is a need to incorporate diverse forms of knowledge to address complex environmental challenges (like innovative adaptation), and that genuine partnerships across knowledge systems are crucial to this endeavor (Morrison and Steltzer 2021, Orlove et al. 2023, Wailoo et al. 2023). But progress has been slow, and just like calls for diverse participation and engagement (Section 6.2.1), these calls will be meaningless without governance mechanisms to enable the full inclusion of diverse forms of knowledge. This is because knowledge systems and governance systems are inseparable; each co-produce the other, in a deeply political sense (Jasanoff 2004), and in so doing, reflect the groups and forms of knowledge that are (and are not) connected to structures of power and thus decisions.

Enabling successful and innovative adaptation in the near and longer term will depend on a much greater awareness of these complex connections across scales, knowledge systems, and worldviews, and how all of the above interact with, and possibly transcend, prevailing structures of power. For example, evidence from many decision contexts to date demonstrates that Western scientific knowledge is often framed and evaluated as having more value, legitimacy, and relevance than Indigenous knowledge, and that the governance and decision-making regimes within which knowledge is evaluated—often designed with, by, and for Western and often colonial systems and ideals—has much to do with this. Furthermore, appropriately engaging with holders of Indigenous knowledge requires care and respect (OSTP and CEQ 2022). The questions below are intended to spark reflection on these issues, and to prompt consideration of how governance systems might be transformed to better achieve the inclusion of diverse forms of knowledge.

6.3.3. Continuous Learning

Processes for effective learning and knowledge management to support shared learning and knowledge exchange within and across institutions and networks.
Barriers addressed: limited knowledge; lack of evidence; resistance to new ideas; poor knowledge transfer.

Having processes in place to support shared and continuous learning is important to fostering innovation, especially in a field that is rapidly growing and evolving, such as climate adaptation. Targeted learning, and in particular learning from failures, creates opportunities for improvement. However, a commitment to viewing failures as important learning opportunities is all too rare, especially within conservation organizations where such reflection is often actively disincentivized and failures are more likely to be concealed than learned from (Guadagno et al. 2021). To counter this inclination, institutions in the medical and military fields embrace what some call "after action reviews" or "pause and reflect" sessions (Guadagno et al. 2021) that offer periodic and systematic opportunities for learning.

Even when learning does happen, such information is not always shared widely due to silos or barriers to communication that form between programs within an institution, or across institutions within a field, or even the challenges of publishing "failures" in the broader literature. A commitment to continuous learning and to sharing knowledge can overcome those barriers and help to accelerate the innovation and improvement process. Mechanisms for rapidly sharing ideas, knowledge, and lessons could include establishing peer learning networks from within and across organizations, and creating venues (e.g., online platforms, virtual webinars, or in-person meetings or conferences) for peers to share what they are doing and learning with each other. Goldstein et al. (2017) describe the benefits of learning networks as including their ability to disrupt existing patterns or behaviors, establish new connections or relationships, and encourage experimentation. Examples include, the Southwest Drought Learning Network, which shares case studies and meets virtually and in person to help network participants learn from each other's past experiences (Elias et al. 2023), as well as the Department of Defense's new National Innovation Landscape Network. A number of other resources are also available focused on sharing adaptation-related experiences and knowledge, including the Climate Adaptation Knowledge Exchange and the U.S. Climate Resilience Toolkit.

Diagnostic Questions

Continuous Learning

- Are the institution and its leaders committed to continuous adaptive learning and improvement, and to incorporating new ideas, observations, and practices as more is learned? Do they accept failure as a learning opportunity?
- Does the institution or program have mechanisms in place to gather evidence, which may include using experimental approaches and controls when appropriate and warranted?
- Does the institution promote documentation, communication, and sharing of knowledge across different programs within the organization? Does the institution (or individuals) participate in external learning networks to support knowledge exchange across institutions?

6.3.4. Commitment to Evidence Gathering

Mechanisms and support for relevant and effective monitoring and evaluation, including processes for determining what needs to be monitored, how, by what metrics, and by whom.

Barriers addressed: lack of evidence; limited knowledge; poor knowledge transfer.

Innovative projects are particularly susceptible to the risk of failure, which makes efforts to measure and monitor their effectiveness especially important (UIA 2020). When compounded with the uncertainties and risks associated with climate change, it is especially critical to gather data on the success and/or failure of innovative adaptation approaches (Peterson St-Laurent et al. 2022). Such monitoring and evaluation efforts create opportunities for learning and improvement (Section 6.3.3), reduce risks associated with adopting new approaches, and ultimately help to determine the readiness of innovative actions for wider deployment (Oakes et al. 2022).

Monitoring efforts are seen as most effective when they are embedded within an iterative, adaptive management process that uses collected data to evaluate action efficacy and, if warranted, revise actions to address any shortcomings (Williams and Brown 2012). In part because climate adaptation involves taking actions today that are expected to affect the future trajectory of a system over longer time periods, it is important to articulate a theory of change or assumptions about how particular actions are expected to result in near- and longer-term outcomes (Margoluis et al. 2013). Indicators that link to the theory of change can be measured to test assumptions and track outcomes. A commitment to long-term evidence gathering, as demonstrated by adopting these and other monitoring and evaluation best practices (Oakes et al. 2022) and allocating adequate sustained funding and other resources, is needed to understand the effectiveness of adaptation actions whose impact will play out over decades of climate change.

Diagnostic Questions

Commitment to Evidence Gathering

- Have time and effort been invested in developing an effective monitoring and evaluation plan (e.g., that defines successful adaptation outcomes, articulates a "theory of change," and identifies metrics to measure near- and longer-term outcomes)?
- Have adequate resources (funding, time, technical capacity) been secured either directly or via partnerships to support long-term evidence gathering?
- Is there a commitment to documenting and sharing evidence regardless of whether it demonstrates success, need for adjustments, or failure?

6.4. Organizational Capacity

Organizational capacity underlies the ability of institutions to carry out their core functions as well as be capable of evolving to tackle emerging issues and seize new opportunities. Indeed, the adaptive capacity of organizations is directly related to their ability to adapt to and respond to changing climatic conditions and conservation needs (Armsworth et al. 2015). Various types of capacity or resource constraints, including time, money, and staff, were identified in Chapter 5 as barriers throughout the innovation lifecycle. Having sufficient resources and suitable expertise are among the most powerful enablers of organizational success overall and to creating a suitable environment to promote innovation. Indeed, having robust organizational capacity is foundational to facilitating virtually all of the above-described enabling conditions. For our purposes, we explore two enabling conditions for organizational capacity:

- Sufficient resources
- Appropriate expertise

6.4.1. Sufficient Resources

Sufficient time to allow for exploration, ideation, and experimentation and avoid the pressure to deploy only the most expeditious, business-as-usual approaches; sufficient funding and material resources to support the creative work of staff and partners, including those historically excluded from such processes.

Barriers addressed: lack of time; limited financial capacity; poor knowledge transfer.

The availability of sufficient time and financial/material resources are crucial to organizational and project success, and key to creating a conducive environment for enabling innovation. Time, in particular, is an underappreciated resource that can be key to creating the conditions under which innovation can thrive.

The relationship between adequate time and sufficient funding is so central to organizational and project success that time and cost are two of the three variables in the well-known project management triangle (also known as the *iron triangle*) (Pollack et al. 2018). Time, cost, and scope represent the three constraints on project implementation and delivery, and when appropriately balanced allow for the creation and delivery of high-quality results. Changing one or more of these constraints (e.g., decreasing time, increasing scope) has a direct effect on the others (e.g., increasing costs) in order to maintain quality.

Adequate time is particularly important to the innovation process. If individuals or teams are operating under serious time pressure, they are unlikely to have the ability to explore alternatives to business-as-usual approaches. This is especially true in the earlier phases of the innovation lifecycle during which exploration, ideation, experimentation, and idea refinement take place. According to Eric Letvin, a Federal Emergency Management Administration official who oversees the agency's pre- and post-disaster mitigation work, "In the rush to spend dollars quickly, innovation goes by the wayside. Innovative projects may take longer or need to do some more design or pre-work." As a result, time is often more readily available for the development of innovative approaches for proactive or anticipatory adaptation. Nonetheless, there is an urgent need to invest in the development and testing of innovative adaptation approaches that can quickly be deployed in emergency or post-disaster circumstances—which is when large amounts of project implementation funds are most often available (see Section 6.1.2).

The importance of adequate time in promoting innovation is perhaps most clearly illustrated in the corporate sector where some companies, such as 3M and Google, have codified the availability of flexible time for staff to explore and work on side projects. Following World War II, 3M adopted the ethos of "innovate or die" and embraced what has become known as its *fifteen percent culture.* In essence, the company encouraged employees to "set aside a portion of their work time to proactively cultivate and pursue innovative ideas that excite them" (3M 2023). This approach is credited with the development of a number of innovative products, including Post-it® Notes. Google adopted a similar approach (at least earlier in its existence), encouraging employees to spend up to twenty percent of their time working on side projects, resulting in the development of such products as Gmail.

Adequate time is also key to engaging stakeholders and rights-holders in participatory planning, research, and innovation processes, and this is particularly true for those from underserved communities or audiences not typically included in such processes. Taking the time to establish trust, and engage in respectful and meaningful ways that adhere to the principles of free, prior, and informed consent (FPIC) is particularly important for engaging Tribal and other Indigenous expertise in adaptation planning processes (Chew and Chief 2023).

Adequate financial and material resources are also key to enabling a supportive environment for innovation. Material resources constitute the fundamental infrastructure of an organization—its facilities, structures, equipment, instrumentation, vehicles, land, etc.—while financial resources include the funding sources and streams that support the organization's staff, infrastructure, and activities. Development and implementation of innovation approaches typically draws from a reapportionment of existing resources or the acquisition of new resources. The extent to which existing resources can be reallocated within an organization to support innovation depends on many factors, including structural constraints (e.g., statutory responsibilities, by-laws) and the fungibility of resources (e.g., donor restrictions on use). The ability to redirect internal resources is a key component of organizational nimbleness but the countervailing forces are often substantial. Developing mechanisms for reviewing success and necessity of ongoing activities, together with fair mechanisms for termination of failing or obsolete projects, and for offloading activities that could be more effectively supported by other organizations, can help free up resources for innovation.

A focus on innovation can also open up substantial new opportunities for acquiring financial resources to support an organization's work. Governmental and private philanthropic funding sources almost universally look favorably on innovation. Not surprisingly, many organizations make use of the term *innovation* in their marketing, fundraising, and labeling of new "innovation centers"—sometimes regardless of its applicability to the work! New resources to support innovative adaptation approaches can also be sought in collaborations and partnerships with other organizations that have a shared interest in the project or intended outcomes.

Diagnostic Questions

Sufficient Resources

- Are there processes or incentives in place that provide individuals and teams with time to explore new ideas or pursue side projects that might lead to innovative solutions?
- Are there processes in place to allocate resources to individuals and teams who are in a position to generate innovation or creative application of established techniques and approaches?
- Are processes in place to ensure that new resources can foster new and innovative approaches, not just augment traditional work and approaches?

6.4.2. Appropriate Expertise

Availability of both specialized expertise as well as staff and partners with varied perspectives, knowledge systems, and expertise; process to support recruitment, retention, and support of diverse leadership, staff, and partners.

Barriers addressed: limited human capacity; operating in silos; lack of diversity; lack of incentives.

The availability of sufficient and appropriate human capital is key to developing and disseminating successful innovations. The skills needed to promote innovation can vary across the innovation lifecycle, however, with early phases often requiring expertise in basic research, problem delineation, systems thinking, and experimentation, middle phases needing skills in technical design, engineering, and stakeholder engagement, and later phases benefiting from expertise in project management, monitoring, and evaluation, as well as knowledge transfer and diffusion. Similarly, climate adaptation requires particular skill sets, perhaps most importantly the capacity to access and understand relevant climate information and projections, which provide the essential context for adaptation planning.

Needed expertise may be sourced from within an organization (i.e., from existing or new staff) or accessed through external partnerships and collaborations. Cross-team collaboration and partnerships (both within and across organizations and including unconventional collaborations) are particularly important because by their very nature, innovations often draw from knowledge, expertise, disciplines, and experiences that may be outside a team or organization's traditional focus and competencies (Berger-Tal and Lahoz-Monfort 2018). Cross-team collaborations and external partnerships can be instrumental in revealing new insights into the problem at hand as well as potential solutions. They can also be key to securing internal support and buy-in for novel approaches, and for promoting the broader adoption of innovations among other organizations and across the sector.

Developing and sustaining partnerships and productive collaborations is a skill itself, and usually requires that both sides of the partnership feel they are benefiting. Those benefits may be financial (e.g., direct funding) or more intangible, as with a sense of tackling a shared challenge or mission. Generosity in sharing of credit among the various partners is essential for sustaining and strengthening partnership and supporting future collaborations. In turn, successful collaborations can lead to recognition of further opportunities for collaborative innovation.

Appropriate expertise can often be recruited from within an organization by tapping into staff with the talent and temperament suitable for taking on new skills and exploring fresh directions and approaches. An organization can also increase its capacity (and nimbleness) for innovation by intentionally recruiting "adaptive staff," screening candidates not only for the skills relevant to short-term organizational needs, but also the interest in and capacity for developing additional skills in the longer term to support innovative initiatives. Organizations can also prioritize training in systems thinking and analysis as well as ideation techniques, neither of which are parts of standard curricula in conservation training. Systems thinking, in particular, is essential for holistic problem framing to ensure that all key elements and relationships are captured, including the human dimensions of the problem.

Creating an environment conducive to innovation also benefits from retaining diverse staff who have demonstrated a commitment to thinking creatively, taking an outcome-focused approach, and adopting a truly adaptive attitude in their work. There are many techniques and human resource policies available to organizations to help in the retention of high-performing staff, which are not in our purview to review here. However, offering opportunities to engage in interesting, impactful, and innovative initiatives can be a powerful incentive for staff retention. Individuals working in the fields of biodiversity conservation and natural resource management, in both government and the nonprofit sectors, are often driven by a sense of mission. Although financial compensation is always a consideration, job satisfaction has many dimensions, including having the flexibility to innovate and making a difference for the resource.

Diagnostic Questions

Appropriate Expertise

- Is the organization open to periodically re-evaluating the skills and competencies of its staff with respect to emerging challenges, and seeking staff in new disciplines and/or nontraditional fields when hiring?
- Are processes in place to ensure that the organization can recruit and retain high-performing and diverse talent interested in exploring novel, outcome-based approaches to emerging adaptation challenges?
- Is the organization positioned to effectively engage outside expertise through partnerships and collaborations, including through sharing of resources and credit?

As climate change accelerates, there is need to consider both the risks of any particular adaptation action—whether new or not—as well as the risks posed by inaction or a continuation of business-as-usual practices. Photo: Hurricane Dorian damage to coastal highway, Cape Hatteras National Seashore, North Carolina. Credit: NPS.

Chapter 7. Assessing and Managing Risks from Innovations

Progress always involves risks. You can't steal second base and keep your foot on first. —Frederick B. Wilcox

As natural resource managers confront the challenge of a changing climate, they face a number of competing pressures. Existing strategies and tactics may become less effective, or even counterproductive, in the face of rapid changes, resulting in the degradation or loss of valued resources. On the other hand, adopting novel approaches to address climate impacts may themselves be ineffective or, worse, lead to harmful outcomes. Consequently, fear of failure, or of harmful outcomes (whether intended or unintended), are major impediments to promoting innovation in adaptation. As noted in Chapter 6, one of the most effective approaches for alleviating these fears is to apply a science-based process for understanding and managing risks that may arise during the course of generating and implementing innovations. To help planners and practitioners do so, this chapter explores some of the fundamental concepts behind risk analysis and looks at how the risk assessment and management process can be applied across the adaptation innovation lifecycle.

7.1. Understanding Risk

Risk, like "innovation," is a concept derived from common usage that has multiple definitions, ranging from general to precise, and which vary among users and applications (Aven 2010). In its most general form, the International Standards Organization (ISO) defines risk as "the effect of uncertainty on objectives" (ISO 2018), while the Intergovernmental Panel on Climate Change (IPCC) offers a core definition of risk as "the potential for adverse consequences" (Reisinger et al. 2020). Formal definitions of risk characterize it as the product of the likelihood (i.e., probability) of some undesirable event occurring along with the consequence (or severity of impact) of the event (Figure 7.1). Something that may be highly likely to occur but that would have little impact would be regarded as low risk, whereas an event with a lower probability of occurring but with serious consequences would be viewed as a higher risk. As implied by the ISO definition, uncertainty (in both occurrence and consequences) underlies the concept of risk.

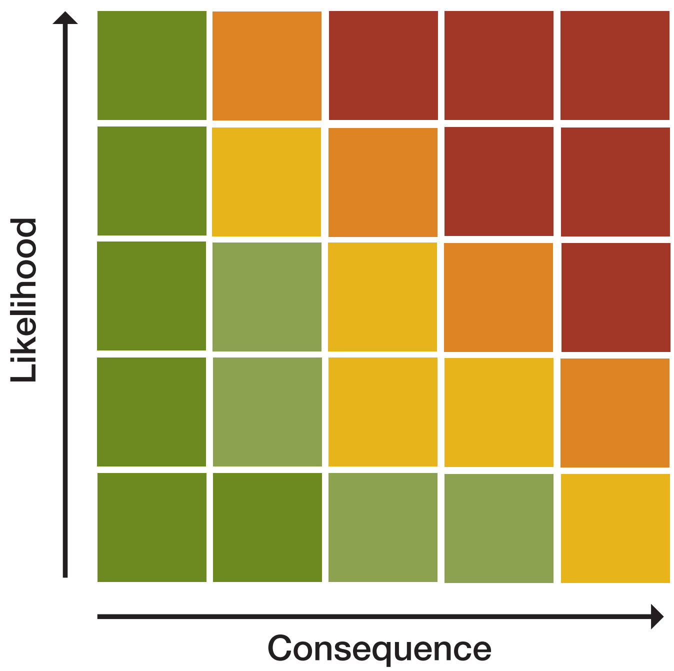


Figure 7.1. Risk is a product of the likelihood an event will occur and the consequence or impact of that event. Higher risk is shown in red and lower risk in green (adapted from NASA 2017).

Risk is multivariate; undesirable outcomes can arise in many forms and at many stages of a project. For that reason, when assessing risk it is important to determine the various junctures at which an innovation might fail, and the sources and consequences of potential failure at each point. Risk is also context specific. Likelihood and adverse consequences change with the specific situation. More importantly, risk does not exist in a vacuum. In any particular decision situation, the risk of implementing an innovation must be weighed against the risk of inaction (e.g., risk of failure by "staying the course"), and the potential benefits (and probabilities) of success under an innovative practice. In many cases, the decision may not be either/or; the risks and potential benefits of an innovation will need to be compared against not just one alternative, but many alternative courses of action.

Climate change poses new challenges for risk assessment, complicating both the assessment of likelihood and consequence (Kunreuther et al. 2013). Traditional risk assessment is usually based on historical data, through assessing probabilities of severity, frequency, and impact based on experience from past events. Such approaches may not necessarily be suitable for characterizing future risks (Adger et al. 2018). The predictive power of historical statistics is largely predicted on an assumption of climatic stationarity, yet in the words of Milly et al. (2008), "Stationarity is dead." Traditional risk assessment also works best in addressing well-defined issues and more familiar systems, and can be challenging to apply in complex systems and under conditions of deep uncertainty (Adger et al. 2018). Indeed, conventional "predict then act" approaches to decision-making tend not to work well in the face of climate uncertainties (Marchau et al. 2019). As a consequence, probabilistic or predictive techniques may be problematic, which has led to the embrace of scenario-based approaches in adaptation planning (Miller et al. 2023), or "possibilistic" techniques in risk assessment (Whalen and Bronn 2008), especially to address the possibility of rare but high-consequence events.

Conservation and management actions almost always entail some level of risk. The goal of risk management is not necessarily to eliminate all risk, but rather to manage risks to an acceptable level. Most agencies and organizations have some process for evaluating the risks (and benefits) posed by alternative courses of action, even if they are not always framed as a formal "risk analysis" and these may make use of both quantitative and qualitative techniques. In addition to formal risk analysis, such approaches can take the form of environmental impact analysis, cost-benefit analysis, trade-off evaluations, or the use of "consequence tables" in structured decision-making processes. Planners and managers must also consider the risk of inaction.[8] Indeed, as climatic conditions change, increasing levels of risk may accrue from not taking needed actions, deferring actions, or continuing to pursue climate-compromised business-as-usual strategies. Consequently, in the face of accelerating climate change, there is an imperative to consider both the risks of any particular adaptation strategy or action, whether new or not, as well as the risks posed by inaction or business-as-usual actions.

7.2. Classes of Risks

There are many types of risks that agencies and organizations must contend with, ranging from the creation or amplification of environmental or social problems, operational disruptions, financial loss, legal liabilities, or tarnishing of reputation/brand. Different sectors (e.g., corporate, government, nonprofits) and disciplines may emphasize certain classes of risk over others, which can complicate general discussions of risk management. As a result, to responsibly manage risks related to novel and innovative adaptation actions, it is important to be clear about the type of risks that are of most concern.

7.2.1. Risks to Biodiversity and Valued Resources

Within the biodiversity conservation community, risk can mean various things. For example, understanding and quantifying the risk of species extinction is one of the dominant themes in conservation biology (Burgman et al. 1993, Mace et al. 2008), and this definition of risk underlies efforts such as the IUCN Red List of Threatened Species and the U.S. Endangered Species Act. Indeed, mitigating the risk of species extinction (and associated risks of ecosystem degradation or collapse) are primary drivers for biodiversity conservation planning and action in the United States and globally. Another type of risk—that conservation or management projects will fail to achieve their intended conservation outcomes—is also well covered within the conservation literature (Game et al. 2013). Finally, the history of natural resource management is littered with a third type of risk: ecologically or socially harmful unintended consequences from well-intentioned initiatives. This phenomenon includes examples such as the introduction of non-native species (e.g., kudzu in the southeastern United States) to address one environmental problem (soil erosion) that then creates new problems (habitat degradation and loss), or management efforts designed to address near-term risks (e.g., historically aggressive wildfire suppression in western U.S. forests) that have led to increases in future risks (e.g., increase in fuel loads and risk of destructive megafires).

Risk also has varying meanings within the climate change community. The dominant usage refers to impacts or threats that climate change poses to communities, livelihoods, and ecosystems. A recent IPCC report on risk noted: "In the context of climate change, risks can arise from potential impacts of climate change as well as human responses to climate change. Relevant adverse consequences include those on lives, livelihoods, health and wellbeing, economic, social, and cultural assets and investments, infrastructure, services (including ecosystem services), ecosystems and species" (Reisinger et al. 2020). An understanding of climate risks is foundational to the practice of climate adaptation, and adaptation measures are often understood to focus on ameliorating climate-related risks and vulnerabilities. Climate risks do not operate in a vacuum, however, and must be considered in the context of interacting non-climate stressors. Indeed, the risks posed by changing climatic conditions are often mediated through their role in amplifying or exacerbating such existing stressors (Staudt et al. 2013). Indeed, the complex nature of ecological systems and their dynamic processes makes it challenging to estimate potential risks from climatic changes, as well the possible consequences of human actions and management interventions.

8 The "no action" alternative is a required element of most environmental review processes, including under the National Environmental Policy Act, which can serve as the basis for evaluating climate risks of inaction.

7.2.2. Risks to Organizational Performance

Organizational risk refers to the potential harm to an organization's ability to achieve its goals and objectives. Organizations vary widely in their risk tolerance, depending on their institutional culture, leadership, mandate, and stakeholders/constituencies. These institutional properties are also important in the risk calculation for innovation. A sufficiently large organization can embed innovative projects within a diverse portfolio, so that even if some initiatives fail or fall short of expectations, other projects can succeed (or get no worse). In some cases, risky innovations may best be deployed in an experimental framework, with controls (e.g., no intervention) or alternatives (different innovations), a monitoring program with specific indicators, and an adaptive learning/decision framework for terminating particular projects or treatments that fail or head in unexpected and undesirable directions and adjusting projects that succeed or move in promising directions.

In a climate context, the vulnerability of particular resources may compromise or undermine the ability of an agency or organization to achieve its mission. For example, in the case of the U.S. Department of Defense, climate change–related loss of forest or coastal habitats can undermine the ability to carry out training exercises and affect military readiness (Stein et al. 2019).

The risk of project failure (i.e., not achieving desired outcomes) can also apply to adaptation projects and initiatives. Beyond being ineffective at reducing risks, however, adaptation measures may actually make a problem worse, an outcome known as maladaptation. Maladaptation can be more formally defined as actions that have the effect of increasing rather than decreasing key climate vulnerabilities, whether on the target of the action, or on nontarget communities or resources (Schipper 2020). More generally, one should consider the potential for harm that may occur from a project or initiative that is executed and operating as designed (i.e., expected outcomes are achieved but may have adverse consequences), as well as harms that may occur from unanticipated consequences (i.e., unexpected outcomes).

7.3. A Framework for Risk Analysis

For the purpose of promoting more creativity and innovation in the practice of climate adaptation, our focus here is on how to assess and manage potential risks or harms posed by novel adaptation solutions. This includes those risks that may be associated with an adaptation that is implemented and functioning as intended. It also includes risks that may be the result of unintended consequences of an adaptation action. Such risks include the possibility that the beneficial effects of an adaptation outcome may be offset or exceeded by maladaptive outcomes that adversely affect either the target resource or community, or other stakeholders, communities, or resources.

There is now an extensive literature, and increasingly legal requirements, for risk analysis across many different sectors and industries that offer insights into the practice of risk analysis. For example, the European Union offers an implementation guide for its risk management policies and practices that offers high-level guidance on the overall risk assessment and management process (EU 2018). However, many risk analysis tools are focused on topics such as food, drug, and chemical safety, financial investments, or insurance, and there is relatively little specific guidance for the application of risk analysis in the fields of natural resource management or biodiversity conservation, especially from a climate adaptation perspective.

Although developed for a somewhat different purpose, a guide to risk-informed planning developed by the U.S. Army Corps of Engineers Institute for Water Resources offers a useful summary of relevant risk assessment and management concepts and processes (USACE 2017). This guide, along with their online Risk Analysis Gateway, provides a number of resources that offer clear descriptions of the application of risk analysis in project evaluation and decision-making, as well as specific training and guidance on the various stages in risk assessment and risk management process. The following discussion of risk analysis draws heavily from this source.

Under this framework, risk analysis typically involves three key tasks (Figure 7.2):

- **Risk assessment—**focuses on defining the nature of the risk, including its probability and consequences. These assessments can be either quantitative, qualitative, or a combination of the two.
- **Risk management—**focuses on the decision-making intended to identify those strategies and actions that can be used to manage risk at acceptable levels.
- **Risk communication—**involves the multidirectional exchange of information to allow a better understanding of the risk by decision-makers and relevant stakeholders.

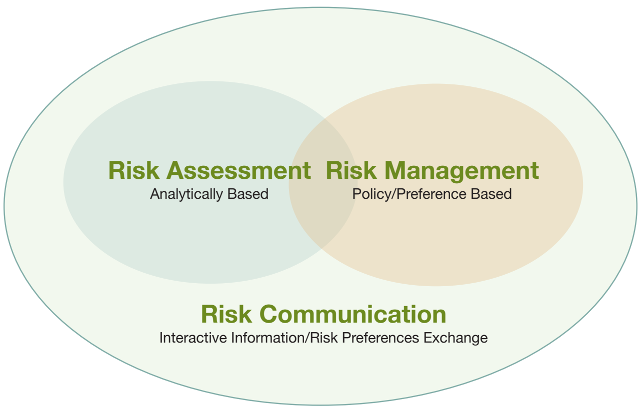


Figure 7.2. Risk analysis includes three key tasks: risk assessment, risk management, and risk communication (from USACE 2017).

In the context of the innovation lifecycle (Figure 3.1), risk assessment will generally take place during the early phases of the cycle (Problem Exploration and Ideation, and Screening and Refinement), as teams seek to identify promising pathways for adaptation that avoid or minimize the potential for undesirable outcomes. *Risk management* will generally take place during the mid- to late phases of the cycle and largely determine which adaptation options are selected for testing and implementation. *Risk communication* is applicable across the entire innovation lifecycle and is generally integrated into the risk assessment and risk management processes. Section 7.4. offers more specific guidance for the application of risk analysis across the innovation lifecycle.

7.3.1. Risk Assessment

Risk assessment represents a core process for identifying potential adverse outcomes from an activity and exploring what the potential severity of the impact would be if it were to occur. Core questions to pose during the risk assessment phase include:

- What can go wrong?
- How can it happen?
- What are the consequences?
- How likely is it to happen?

Answering these questions can be done based on a structured set of analyses that involve: 1) identifying potential risks; 2) assessing the consequences and likelihoods; and 3) characterizing the risks. The level of detail and rigor in the risk assessment phase will depend in part on where in the innovation lifecycle and decision-making process this takes place. Assessing risks during the discovery and ideation phase of the cycle may be more rapid and informal, serving as a quick tool to determine whether possible ideas may pose serious or even catastrophic risks and should be discarded. Assessing risks during the screening and experimentation phase of the lifecycle will likely deserve more rigor and scrutiny, since this will serve as the basis for evaluating whether to advance an idea or approach into testing, piloting, or implementation.

Identify risks. During this stage in the risk assessment process, all possible risks, impacts, and adverse outcomes associated with the action or innovation under examination should be identified, to the best of the team's ability. This should include those risks that may reasonably be anticipated if a project were carried out as designed and if it functions as expected. It should also include a best effort to identify risks that may occur or be triggered as a result of unintended consequences. The set of potential impacts should include both existing and emerging risks, new risks, as well as risk transfers (i.e., shift in the risk burden from one sector or group to another). Once the risks are identified, a risk profile can be developed that describes what is known and not known about the risk, which can then help to scope whether a more detailed assessment of the risk is required. Such a profile may also reveal the need to gather additional information about the risk or conduct new research to fill in needed gaps in information.

Assess consequences and likelihood. Estimating the consequence and likelihood of identified risks can be challenging, however, and both quantitative and qualitative approaches can be used. Although the focus on likelihood and probability may imply the use of quantitative approaches, in many instances qualitative approaches can be appropriate, based on subject matter expertise, expert elicitation, or other approaches. This is particularly the case if assessing risk is part of a scoping of alternatives during early phases of the innovation process. Indeed, even scoring likelihood and consequence with a basic high-medium-low approach can offer a general understanding of relative risk appropriate for these uses. Should innovations with the possibility of higher risks be identified, additional research and more sophisticated analytical approaches can then be applied to better document, characterize, and bound the level of risk.

Characterize risks. A risk characterization or description draws from the assessment of consequences and likelihoods to offer a narrative explanation that puts it into a context that decision-makers and others can understand. The risk characterization should note any uncertainties inherent in the assessment, the implications of those uncertainties for bounding risk levels, and for determining additional research or information that might be needed to reduce those uncertainties and improve the robustness of the assessment for use in the risk management and decision-making process.

7.3.2. Risk Management

The process of risk management takes the results of the risk assessment and puts it into an evaluation and decision-making context. With respect to the innovation lifecycle, the risk management process is where potential innovative solutions can be evaluated to determine, based on their risk profile, whether the innovation has potential and should be explored and developed further, whether it should be modified to reduce those risk profiles, or whether risks are so great the idea should be abandoned altogether. As previously noted, there is almost always some element of risk associated with conservation and adaptation actions, and the need is to achieve desired outcomes and goals while managing risks to an acceptable level. What is an acceptable, or tolerable, level of risk is a social rather than scientific question, however (see Section 6.2.2). For that reason, although risk assessment is largely an analytically based process, risk management is fundamentally a policy, preference, or values-based process (Figure 7.2). Indeed, acceptable levels of risk may vary depending on the perspectives or viewpoints of different stakeholders and rights-holders (see Section 6.2.1).

Although adaptation measures generally are intended to reduce climate risks of one type or another (or take advantage of opportunities), an evaluation of how effective any given measure is in achieving those risk reduction outcomes is a key part of the process for evaluating possible adaptation approaches. Nonetheless, our focus here is on risk management in the innovation cycle, and in particular on addressing the risk of adverse outcomes from the innovations themselves.

There is a suite of options available for managing risks, ranging from complete elimination or avoidance to acceptance. The most common risk responses are:

- **Reduction—**Reducing risks to acceptable levels can be accomplished through addressing the cause, or mitigating the consequence, of the risk. Despite such a reduction, there may still be some level of residual risk.
- **Acceptance—**Acceptance implies a level of risk tolerance in which the risk is determined to be of acceptable levels and no action is needed to reduce or mitigate the risk.
- **Avoidance—**Avoidance can be accomplished through a redesign of actions to eliminate the particular risk of concern, or can be achieved by discarding plans to carry out the activity or action altogether.
- **Transfer—**Risk transfer is designed to share the risk with other parties, such as through the use of insurance. Transference of risk, however, can also be maladaptive, such as where an action in one place simply displaces those risks to affect others (e.g., construction of upstream levees can increase downstream risks of flooding).

Risk evaluation and acceptability. The risk evaluation stage of the process focuses on determining whether or not the risks are likely to be acceptable from the perspectives and values of relevant decision-makers or affected stakeholders and rights-holders. An acceptable risk is one that can be accepted as is and would not be regarded as having major impacts. In contrast, tolerable risks are considered as having more potential impacts than are widely acceptable. As the Institute of Water Resources risk guide states: "A tolerable level of risk is one which is grudgingly accepted in order to secure certain benefits" (USACE 2017). It is also possible that unacceptable levels of risk may be reduced to at least a tolerable level. Engagement of diverse stakeholders and interest groups in the innovation process is key to being able to understand their risk tolerances, and what types and levels of risk they may find acceptable, tolerable, or altogether unacceptable/intolerable (see Section 6.2.1).

The main elements of the risk evaluation step include the following:

- Determining whether the risks are acceptable to the decision-makers and/or to the affected rights-holders and stakeholders.
- Crafting risk management options for those risks deemed unacceptable. This can include options for reducing the impact or likelihood of risks from a potential innovation.
- Evaluating risk management options to identify trade-offs and the most appropriate way to address the risk.

Risk management decisions. The final step in this process is to apply the preceding risk assessment and evaluation in the decision process at hand. In the context of the innovation lifecycle, this will often take the form of deciding which options that have emerged from the discovery and ideation process have sufficiently acceptable risk profiles to explore and develop further, or even to move into piloting or full-scale implementation. This generally involves comparing all viable options against one another from the perspective not only of risks the innovations may pose, but more broadly their likely effectiveness in achieving desired adaptation outcomes, their potential costs and feasibility, as well as their capacity to deliver other desirable societal benefits or co-benefits. Again, the level of analysis and rigor in such comparisons increases as one moves through the innovation lifecycle, so as not to unduly hamper early, exploratory phases. However, as innovations reach a point where they may be experimented with or piloted "in the wild," greater rigor and attention is needed for assessing risks, evaluating the acceptability of those risks, and/or developing risk management strategies to ensure that any risks of harmful outcomes—expected or unintended—are considered and mitigated.

7.3.3. The Precautionary Principle and Innovation

The precautionary principle is an approach to risk management—or risk avoidance—that has been embraced in a number of policies and international treaties. It has been mostly applied when considering the potential environmental and public health impacts of new products, technologies, or industries. The principle generally is considered to have four central components: taking preventive action in the face of uncertainty; shifting the burden of proof to the proponents of an activity; exploring a wide range of alternatives to possibly harmful actions; and increasing public participation in decision-making (Kriebel et al. 2001). Although there is wide variation in how the precautionary approach is defined and applied, it generally focuses on plausible harms for which there is significant scientific uncertainty. That said, because of the widely divergent ways in which the principle is applied, its application can be controversial. Indeed, it is often wielded as a weapon (including by those adhering to fringe or conspiracy theories) and invoked even when there is a relatively high level of scientific understanding and certainty. In its strongest formulations, the principle can be interpreted as calling for absolute proof of safety before allowing new technologies to be adopted (Foster et al. 2000). In contrast, the landmark 1992 Rio Declaration notes that lack of "full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation," and climate adaptation actions intended to reduce climate risks to species and ecosystems can be considered to fall into this category.

Because of the emphasis on risk avoidance and a perceived standard of "proof of safety," the precautionary principle is often viewed as stifling innovation (Bourguignon 2015, Hemphill 2020). Furthermore, given the emphasis on risk avoidance, rather than risk management, there is also a concern that if applied in its most extreme forms the principle ignores or downplays the risk of inaction related to accelerating climate risks (Hopster 2021). Nonetheless, if applied in a more moderate form, the principle's general precepts of exploring alternatives to possibly harmful actions and increasing public participation in decision-making can be consistent with promoting responsible risk-taking in the practice of climate adaptation. In the context of climate change, it's not always clear which pathway is "precautionary," avoiding intervention out of concern for harmful side effects and allowing the impacts of climate change to proceed or mitigating climate impacts at the risk of having some unintended consequences that need to be quantified and minimized (Schwartz et al. 2009).

7.4. Managing Risks Across the Innovation Lifecycle

Ideally, adaptation solutions developed through the innovation process would offer substantive reductions in climate-related risks to the target resource but pose little or no risk of harm themselves. Because that will not always be the case, there is a need to apply the concepts of risk analysis across the innovation lifecycle (Section 3.1). Different components of the risk analysis process, however, are relevant to different parts of the cycle. In general, risk assessment and characterization apply most to earlier parts of the cycle, while risk evaluation and management are most relevant to middle and latter cycle phases. Below, we offer some observations and considerations for the application of risk analysis to these different phases of the innovation lifecycle.

Innovation Phase 1—Discovery and Ideation. The emphasis of Phase 1 of the cycle is on problem exploration and idea generation. As such, there is a premium on unfettered thinking and creativity in order to generate multiple, divergent possible solutions to the problem at hand. The focus at this stage tends to be on the potential benefits and effectiveness of the possible solutions, rather than on their risks and potential downsides. That said, it is worth considering whether any of the ideas generated during this phase would pose catastrophic harm or depend on illegal or unethical actions. Such "beyond-the-pale" ideas are unlikely to prove feasible or useful and can probably be eliminated from further consideration unless a variation of the concept might be found that substantially addresses the problem.

Innovation Phase 2—Screening and Refinement. While the goal of Phase 1 is to generate as broad and divergent a set of possible options and solutions as possible, the intent of Phase 2 is to evaluate and screen those ideas to determine which have further potential. Those with potential can then be refined, prototyped, and tested. It is during this phase that risk assessment and characterization is most relevant, serving as a core component of the idea evaluation and screening process. Assessing the risk of harm (from both expected outcomes and unintended consequences) serves two purposes during this phase of the innovation lifecycle. First, it can help eliminate ideas that pose unacceptably high risks, particularly if there is not an expected high-level of benefit from the action. Second, by revealing anticipated risks it can serve as a basis for additional research and refinement designed to further reduce those risks. Because this phase of the cycle also can include prototyping and testing, there is a certain level of risk evaluation needed to determine if risk levels for a particular concept are acceptable even for testing in limited or controlled environments. If not, then additional research might be needed to further modify or refine the concept before it can be safely prototyped and tested. Processes for evaluating and comparing different risk tolerance among stakeholder groups may also be necessary at this phase of the process (Richardson et al. 2009).

Innovation Phase 3—Implementation. Determining whether an adaptation innovation is suitable for implementation, whether as a pilot or at scale, depends on an evaluation of the likely effectiveness of the action at addressing the problem as well as levels of risk associated with the action. In essence, do the benefits of the action (in terms of climate risk reductions and conservation outcomes) outweigh the potential harms of the action? For this reason, decisions around risk management are central to this phase of the innovation lifecycle. Based on an evaluation of identified risks, does the action pose levels of risk that relevant decision-makers and stakeholders deem acceptable—or at least tolerable, including when compared with the risk of no action? If not, it may be necessary to return to Phases 1 or 2 to identify lower-risk alternatives or explore whether there are any opportunities to modify the proposed option to reduce expected risks to acceptable levels.

Because risk evaluation is based not just on scientific analysis but also on an understanding of social values and perceptions, there is an important role for engagement with relevant stakeholders and rights-holders prior to implementation, and for effective risk communications to clearly describe what is known and not known regarding risk profiles and potential harms. As part of these communications, it is also important to clearly convey any risks associated with inaction on the problem so that the risks posed by a given action can meaningfully be compared with the risks from delay or inaction.

Monitoring the results of implemented projects and actions is also important to document whether previously identified risks are occurring, or whether there may be unintended adverse outcomes. Monitoring and evaluation are core to the adaptive management process, and serve to help managers refine and adjust strategies and actions based on their effectiveness at achieving intended objectives as well as any adverse or unexpected outcomes that may become apparent. If that is the case, additional risk management decisions may be needed, which can run the gamut from halting implementation altogether (in the case of the emergence of unacceptable or intolerable risks) to modifying project designs or timelines or instituting additional safeguards or risk management measures.

Innovation Phase 4—Diffusion and Adoption. The broader diffusion and adoption of a new strategy or technique is usually contingent on its successful application in pilots as well as full-scale implementation. From a risk management perspective, it is also important to identify any circumstances or contexts (ecological and/or social) in which an action could pose a higher level of risk, and therefore would not be appropriate. An adaptation action might, for instance, have a relatively low risk of adverse impacts if applied in one region or ecosystem type, but pose higher risks if applied in a different region. As an example, a risk assessment of genetically modified (GMO) cotton in Mexico determined that the risk of gene transfer to wild cotton would be low if cultivation of GMO varieties were restricted to regions without native cotton species (i.e., northern Mexico) but unacceptably high if planted where native cotton is found (Rocha-Munive et al. 2018).

Coastal marshes along the Chesapeake Bay's Blackwater National Wildlife Refuge are being lost to rising sea levels, and are the focus of a number of novel adaptation actions. Credit: Westend61 GmbH/Alamy.

Chapter 8. Innovation in Action: Case Studies

Throughout this guide we explore a range of concepts related to the theory and practice of innovation. To help connect these concepts to on-the-ground conservation and resource management, this chapter profiles several real-world examples of innovative adaptation in action. The chapter examines how practitioners working in a range of geographies and ecosystems have developed novel adaptation approaches to address emerging climate-related risks.

By describing the processes used by these practitioners in developing, refining, implementing, and/or assessing novel adaptation approaches, the case studies illustrate various pathways across the innovation lifecycle (Section 3.1). Of particular note are the barriers to innovation encountered by these practitioners and how they were able to overcome those hurdles. To that end, the case studies highlight some of the most relevant enabling conditions (Chapter 6) and other factors that allowed for these innovations to be put into practice. Table 8.1 summarizes the case studies and highlights the enabling conditions featured in each.[9]

8.1 Coastal Marsh Adaptation on the Chesapeake Bay

The Chesapeake Bay is the largest estuary in the United States and, at least historically, one of the most biologically productive water bodies in the world. The bay's vast coastal marshes are a magnet for migrating waterfowl and support an array of rare species, from bald eagles and saltmarsh sparrows to the secretive

Spraying sediment from the Blackwater River to raise the base elevation of marshland, boost plant productivity, and prolong the marsh's expected life. Credit: Middleton Evans/USFWS..

[9] These case studies draw from publicly available documents, supplemented in most cases by interviews with individuals involved in the projects. The interview protocol and related aspects of the research study plan were reviewed and approved by the Wildlife Conservation Society's Institutional Review Board. The interview protocol is available upon request.

Table 8.1 Summary of case studies.		
Case Study Title	**Location and Ecosystem Type**	**Enabling Conditions Featured**
Coastal Marsh Adaptation on the Chesapeake Bay	Maryland, USA; salt marshes and mixed hardwood/pine forests	• Committed and supportive leadership • Novel insights • Varied expertise and diverse perspectives • Continuous learning • Transparency in trade-offs
Climate-adapted Forestry in Minnesota's Northwoods	Minnesota, USA; boreal forest/ temperate forest ecotone	• Open to taking risks • Sufficient resources and capacity • Inclusion of rights-holders and stakeholders
Tribal-led Beaver Relocation for Salmon Habitat Enhancement	Washington, USA; Puget Sound riparian forests and watersheds	• Committed leadership • Rights-holder participation and diverse perspectives • Commitment to evidence gathering • Transparency in trade-offs
Novel Fire Protection in a Tasmanian Wilderness	Tasmania, Australia; paleoendemic plant communities	• Novel insights • Open to taking risks • Transparency in trade-offs • Sufficient resources
Protecting Carbon-rich Permafrost in the Yukon	Alaska, USA; boreal forest and yedoma (ancient carbon-rich permafrost)	• Committed leaders and culture of trust • Open to taking risks • Nimble and adaptive • Continuous learning and diverse perspectives

black rail. Situated on the bay's eastern shore, Blackwater National Wildlife Refuge (NWR) harbors one of the most extensive marsh complexes on the bay. Established in 1933 as a waterfowl sanctuary, the refuge now covers more than 32,000 acres consisting of tidal marsh, mixed hardwood and loblolly pine forests, freshwater wetlands, and agricultural fields. This is also a culturally and historically significant area, with Harriet Tubman's childhood home nearby, and forests and marshes now a part of the refuge believed to have been used as hiding places by enslaved Black people traveling north to freedom on the Underground Railroad.

Over the past several decades the refuge has been losing extensive areas of its signature marshes: about 5,000 acres of tidal marsh have converted to open water since 1938 (Lerner et al. 2013). There are several reasons for this high rate of marsh loss. Nutria, a non-native rodent from South America, was introduced to Blackwater NWR in the 1940s, originally for fur farming. The species became invasive in the region, and its burrowing and foraging activity has accelerated erosion and led to the degradation or loss of wetlands across the Chesapeake region. Additionally, sea-level rise is outpacing the rate of natural sediment accumulation, hindering the ability of low-lying tidal marshes to remain above water. The Mid-Atlantic region is a hotspot of accelerated sea-level rise, with rates about twice the global average due in part to the influence of geologic (isostatic) land subsidence (Sallenger et al. 2012).

Because of the effect of sea-level rise on Blackwater's marshes, the refuge emerged as an early symbol of the impacts that climate change is having on the nation's wildlife and conservation areas. Countering that image, Blackwater has now become a symbol of innovative climate adaptation. Indeed, many of the enabling conditions and other findings highlighted in this innovation guide can be seen to be in play in the refuge, and its many and varied partners are tackling this challenge.

8.1.1. A Vision for Blackwater National Wildlife Refuge

A coalition of partners led by the nonprofit Conservation Fund carried out an adaptation planning process for the refuge that set about identifying opportunities to not only slow the loss of tidal marshes, but to ensure the capacity for marshes to move and re-establish as the tide rises (Lerner et al. 2013). The resulting "Blackwater 2100" plan took advantage of newly emerging scientific information on marsh loss and resiliency to propose a set of adaptation measures—both conventional and novel—that broadly align with the RAD (resist-accept-direct) framework (Schuurman et al. 2022). Resistance-oriented strategies include: 1) targeted increases in marsh elevation through the use of thin-layer placement of sediment; and 2) nutria eradication efforts throughout the region. The plan also identified several transformation-oriented (i.e., "direct") strategies designed to facilitate the ability of marshes to move inland and upslope as tides rise. These include: 1) removal of trees in transitional or "ghost" forest areas to improve adjacent marsh habitat for birds and facilitate upland marsh transition; 2) early detection and control of invasive *Phragmites* in forest and field areas to allow for a transition to native marsh grasses; and 3) switching plantings on row-cropped agricultural land to salt-tolerant switchgrass to avoid *Phragmites* invasions and facilitate the transition to natural marsh.

The Blackwater 2100 plan not only sets out a vision for what could be done, but over the past decade the U.S. Fish and Wildlife Service and its partners have been implementing an array of projects based on those strategies. This has included carrying out an experimental 40-acre thin-layer sediment placement project at Shorters Wharf to raise the base elevation of the marsh, boost plant productivity, and prolong the expected life of the marsh. Other projects have included the proactive removal of dead and dying trees to determine if doing so facilitates establishment of open marsh conditions desirable for key at-risk bird species. The Service and its partners have also been waging a concerted—and ultimately successful—effort to eliminate marsh-destroying nutria from the refuge, and are actively spot treating *Phragmites* invasions in forest understories that are transitioning to wet marsh.

8.1.2. Enabling Conditions for Innovation

The ability of Blackwater NWR to mount a sustained and innovative response to climate change–related loss of tidal marshlands has been enabled by many of the factors and conditions described in Chapter 6.

Committed and supportive leadership. Perhaps most importantly, refuge leadership challenged and empowered its staff to think creatively in addressing these existential threats to the refuge's wildlife values. Indeed, the refuge manager is said to have informed her staff that she wanted to shift the image of the refuge from being a poster child for climate change–related loss, to an illustration of effective adaptation and active responses to the climate challenge. Supportive leadership allowed the refuge to fully engage with varied partners in trying unconventional, and sometimes risky, ideas.

Novel insights. Scientific advances in understanding the extent and functioning of Blackwater's marshes and the causative agents in their decline offered insights that could be directly translated and used in the development of adaptation responses. Mapping the historical, current, and projected future marsh extents allowed the project team to reconsider and reframe the problem at hand. In essence, the challenge expanded from an emphasis on threats to and loss of existing marsh to opportunities presented by newly emerging, migrating marshes. Another set of studies elucidated the concept of “elevation capital” (the elevation of the marsh surface relative to the lowest elevation in the local tidal range at which native marsh plants can survive), a metric of marsh adaptive capacity that was pivotal in identifying targets for elevating marshland through thin-layer placement of sediment (McCullough et al. 2021). And in contrast to many previous thin-layer placement projects, this insight also led the team to focus on elevating and enhancing marsh that was deteriorating but still intact (i.e., at the lower end of its elevation capital), rather than on areas that already had transitioned to mud flats.

Varied expertise and diverse perspectives. The adaptation efforts at Blackwater have benefited from the broad institutional partnerships involved. This includes U.S. Fish and Wildlife Service staff and regional experts as well as nonprofit organizations such as The Conservation Fund and Audubon Maryland-DC who spearheaded the original planning effort and have raised funds for implementation of specific projects. Innovative adaptation work on the refuge has also benefited from the varied technical expertise provided by an array of other federal and state partners, including the U.S. Army Corps of Engineers, U.S. Geological Survey, and the State of Maryland’s Department of Natural Resources. Indeed, addressing adaptation needs in this complex ecological, cultural, and historical landscape benefited from such varied expertise and disciplinary specialties as marsh ecology, ornithology, hydrology, engineering, communications, and community engagement.

Continuous learning. Many of the adaptation strategies and projects being undertaken at Blackwater are still experimental in nature and designed to shed light onto whether the approaches can be successfully implemented and whether they are producing the intended outcomes and benefits. As an example, there has been extensive monitoring of the Shorters Wharf thin-layer placement project to understand how successful the effort was in achieving elevational targets, enhancing marsh plant growth, and improving habitat for and utilization by target bird species (Whitbeck et al. 2019). The tree-removal project, designed to facilitate inland marsh transition and improve open marsh habitat for at-risk birds, is perhaps one of the most unconventional and experimental adaptation efforts undertaken at the refuge. Although the project was successful in creating open wet-meadow and marsh, monitoring found that it did not draw in the at-risk bird species being targeted. As a result, although promising conceptually, this experimental approach to facilitating ecosystem transformation is unlikely to be carried out at scale.

Transparency in trade-offs. Among the most challenging problems at Blackwater is the presence of *Phragmites australis* (common reed), an invasive grass that aggressively establishes in disturbed tidal wetlands, choking out and displacing native marsh plants. *Phragmites*-dominated marshes offer little value as wildlife habitat, and for many years resource managers have focused, where possible, on its control and removal through both chemical and physical means. More recently, however, *Phragmites* has been recognized for the value it can provide in stabilizing shorelines, reducing soil erosion, and storing carbon (Kiviat 2013). As a result, determining how and where to manage *Phragmites* on the refuge has emerged as a key adaptation issue, particularly given the central focus of the area as a sanctuary for waterfowl and at-risk species. For this, refuge adaptation strategies are particularly focused on preventing the establishment of the reed in newly emerging, migrating marshes rather than attempting to remove it from currently infested areas.

The Blackwater NWR case study demonstrates how supportive leadership, broad and varied partnerships, and targeted scientific investigation and exploration can lead to the development of creative and forward-looking adaptation planning and implementation.

8.2. Climate-adapted Forestry in Minnesota’s Northwoods

The northern part of the Great Lakes region of the United States sits in the ecological transition zone between cold-adapted boreal forests to the north and more temperate forests to the south. These Northwoods ecosystems are currently dominated by boreal trees such as quaking aspen, paper birch and several conifer species, but they also harbor more temperate tree species including eastern white pine, sugar and red maples, yellow birch, basswood, and red and bur oaks. Forests in the region are culturally and economically important, support clean air and water resources, and provide habitat for a diversity of wildlife, especially conifer-dependent songbirds. Models of vegetation changes under future climate scenarios project that as temperatures rise boreal species are likely to decline, while temperate trees will increase in abundance (Handler et al. 2014). Some more extreme scenarios suggest that warming and other related climatic changes could trigger a loss of forest cover and conversion to shrubland or grassland in some areas. For these reasons, it is likely that the effectiveness of traditional conservation practices, which have largely focused on restoring boreal conifer-dominated forests, will be compromised by a changing climate.

As climate change alters the composition of forests in northern Minnesota, researchers and landowners are experimenting with novel approaches to forest restoration. Credit: Daniel Thornberg/Alamy.

8.2.1. Novel Approaches to Forest Restoration

To maintain thriving forest ecosystems and the values and resources they support, conservation organizations, natural resource managers and landowners in northern Minnesota are experimenting with novel approaches to forest restoration. These approaches take an intentional and science-based approach to deciding where and how to help boreal forests persist, and where to implement actions designed to direct a transition toward new, yet still-desirable forest conditions.

At sites deemed most likely to sustain boreal forest species and habitat as the climate changes (Anderson et al. 2014), The Nature Conservancy and their partners are testing innovative modifications of traditional reforestation practices designed to allow those forests to maintain boreal species. These sites include ones that are relatively colder than the regional average, ones that have a high diversity of landforms (e.g., slopes, aspects, bedrock types, soil types, soil moisture levels), or both. In these “conifer stronghold” locations, forest restoration designed to enhance genetic diversity of boreal conifers, by sourcing seeds from warmer areas farther south (e.g., Wisconsin), is being evaluated to see if a move away from the traditional “local is best” seed sourcing approach could support the persistence of a northern boreal conifer component in at least some forested landscapes in the region.

At sites where the risk of boreal species loss is projected to be greater, innovative reforestation practices incorporate results from climate change forecast models when selecting trees and seeds for enrichment and restoration plantings. This includes planting more tree species that are native to the region but are projected to thrive under future climate conditions (e.g., oaks, white pine, yellow birch, basswood), as well as sourcing those seeds and seedlings from areas that have a climate that is more similar to what is projected for northern Minnesota in the future. With this approach, practitioners are embracing changes in the composition of Northwoods forests while trying to avoid the complete loss of forest cover and related ecosystem services.

These new approaches to reforestation in the Northwoods have progressed through the innovation lifecycle (Chapter 3) to the implementation phase (Phase 3), with demonstration projects in place and data being gathered on the effectiveness of these actions. Partners are also laying the groundwork for diffusion and adoption (Phase 4) of these novel and climate-informed reforestation techniques. Along the way, practitioners have worked their way through challenges, barriers, and oversights. Early in the development and testing of these ideas, concerns about adopting new approaches to species and seed selection were common. As the work progressed, it became clear that having adequate access to climate-adapted seeds and seedlings from nurseries in the region was a critical barrier to adopting the approach across larger areas. It also became apparent that there were value systems and knowledges that were not considered in early demonstration projects. For example, the selection of tree species for planting was initially based on the results of future climate suitability models; these pilot efforts did not include input from other sources, such as Indigenous knowledge and biocultural values. As a result, even though these demonstration projects showed some promising ecological outcomes, the specific design of the approach being piloted was of concern to some because it failed to meet values of importance to rights-holders and stakeholders in the region. A few of the species included in early climate adaptation plantings were even deemed by some to be nuisance species.

8.2.2. Enabling Conditions for Innovation

Practitioners involved in this work highlight a few factors they believe have enabled progress in addressing these concerns and challenges to date, and conditions that they believe will be necessary to collaboratively designing and scaling up climate-adapted forest restoration in the region.

Open to taking risks and continuous learning. Risk-taking has been and will likely continue to be critical in helping to advance climate-adapted reforestation. Even though the approach is uncommon and its success will not be known for many years or even decades, the willingness of practitioners in the conservation and forestry communities to consider adopting forward-looking approaches to plant selection has increased over roughly the past decade. The reasons for this shift in risk tolerance are not perfectly known but may include the increasing visibility of forest changes due to climate change (e.g., fire, pests, flooding) and a growing recognition that new approaches may be necessary, the field becoming populated with individuals who are more willing to accept ambiguity and uncertainty, and that as people become more familiar with climate-adapted reforestation techniques through discussions and pilot projects, their comfort increases (i.e., "familiarity breeds comfort"). It also may reflect increasing support for "trial and error" learning where negative outcomes are not considered "failures" but rather learning opportunities.

Sufficient resources and capacity. Without a reliable and sufficiently abundant source of seeds and seedlings from species projected to thrive under future climate conditions and/or that were collected in warmer provenance zones, the innovative strategies being tested by The Nature Conservancy and their partners cannot be implemented at scale. Therefore, a key aspect of this work aims to develop and build the capacity of local and regional nurseries to increase the production of climate-adapted seeds and seedlings. This component of the effort is also likely to involve risk-taking. For example, plant nurseries may need to adjust the seeds and species they are growing to increase the provision of climate-adapted seeds and species without financial assurances or security (i.e., knowing in advance who will purchase the seeds and plants, and how much they will purchase).

Inclusion of rights-holders' and stakeholders' values and knowledge. A critical component necessary for the long-term durability and success of this work is the co-creation of solutions in and with the communities who are most impacted by canopy loss and who have the deepest knowledge of place. Based on feedback during pilot efforts, the team took a pause to better situate these strategies in this context. This will be an on-going process as forming authentic and reciprocal relationships with new partners takes dedicated effort and a breaking down of paradigms that are inherently self-serving to only some interests.

This case study of climate-adapted reforestation in Minnesota illustrates the iterative nature of innovation, and how leveraging shifts in risk tolerance and support for learning, securing adequate resources, and co-creating strategies with rights holders and stakeholders are critical to that process.

8.3. Tribal-led Beaver Relocation for Salmon Habitat Enhancement

Salmon are of central importance to the livelihoods, health, and culture of the Indigenous Peoples of the Pacific Northwest, and an essential component of the region's coastal and riparian ecosystems. They play multiple roles in the food web—as predators, prey, and nutrients—and are integral to regional cultures and economies. Salmon are also very sensitive to climatic changes, especially to altered thermal and flow regimes in their spawning streams. Extensive research has been conducted to evaluate the vulnerability and implications of climate change on salmonids (e.g., Crozier et al. 2019, Reid et al. 2022), with actions to reduce those climate vulnerabilities just beginning. Some actions are modifications of past conservation approaches (e.g., reducing instream withdrawals, protecting riparian canopy cover), whereas others reflect newer approaches, including the reintroduction of beavers to watershed from which they have been extirpated.

8.3.1. Beavers as Ecosystem Engineers

For millennia, beavers played a keystone role in the creation and maintenance of streamside and wetland habitats that support salmon and a vast array of other fish and wildlife species. Hydrological benefits of beaver activity include groundwater recharge, buffering of habitats against drought, creation of cold-water refugia for fish in the deeper waters of pools and ponds, stormwater regulation, and sediment storage (Morrison et al. 2015). Over the past two centuries, however, beavers across North America have largely been viewed as either a source of profit for their pelts or as a nuisance for flooding agricultural lands and human infrastructure. As a result, beavers were nearly extirpated across the country, resulting in a loss of the critical ecosystem services they provided for habitat creation and hydrological functions (Wohl 2021).

As part of the Tulalip Tribes' beaver reintroduction project, biologists carry two beavers to their new lodge in a creek near the Skykomish River, Washington. Credit: Northwest Treaty Tribes.

Over the past two decades there has been a dramatic increase in recognition and appreciation of the function beavers play as ecosystem engineers and their importance for creating, restoring, and maintaining fish and wildlife habitat, including for salmon (Bailey et al. 2019). Beavers are increasingly valued for their role in climate adaptation, representing a nature-based solution to reducing climate risks from flooding and drought. Beaver activities help store and recharge water in the landscape, particularly in drought conditions, and wetland and riparian areas created by beaver can function as natural firebreaks in areas threatened by climate-driven increases in wildfire frequency and severity. Beaver reintroductions and use of beaver dam analogs play an important role in the innovative ecological restoration approach known as *low-tech process-based restoration*, which represents an alternative to traditional forms of engineering-based stream restoration (Wheaton et al. 2019).

8.3.2. The Tulalip Beaver Project

The Tulalip Tribes of Western Washington are a salmon-based culture, and the collapse of salmon populations in the region is a cultural and spiritual threat to the Tribes' identity. The Tulalip are direct descendants of and successors to the Snohomish, Snoqualmie, Skykomish, and other allied bands that were signatories to the 1855 Treaty of Point Elliott, and are located on a 22,000-acre reservation along the shores of the Puget Sound. Under treaty rights, the Tribes retained fishing and hunting rights, and federal courts have ruled that the Tribes, along with the State of Washington, have co-management responsibility and authority over fish and wildlife resources. The Tulalip Tribes Department of Natural Resources is committed to using traditional stories and teachings alongside the best available science to protect, honor, and restore ecosystems for the health of its people (Tulalip Tribes 2023a).

The Tulalip Beaver Project is an innovative approach for restoring fish habitat and helping to recover the salmon populations on which the Tribes rely (Tulalip Tribes 2023b). In partnership with the U.S. Fish and Wildlife Service and the Washington State Department of Fish and Wildlife (WDFW), the Tribes are relocating nuisance beavers from farms and developed areas to hydrologically impacted watersheds in the upper Snohomish watershed. According to Jason Shilling, a Tribal wildlife biologist, "The Snohomish ecosystem is the second-largest salmon-producing system in Puget Sound and there are some limiting factors for salmon production, the biggest ones are water temperature and sedimentation…It just so happens that beavers are very good at fixing those problems" (Thomas 2015).

The Tulalip's efforts to deploy beavers to improve headwaters salmon habitat had to overcome significant barriers, particularly from restrictive policies and laws. When the Tulalip started this project, beaver relocation was illegal in Western Washington. Although a Washington State "Beaver Bill" was enacted in 2012 that recognized the ecological importance and restoration potential of the animals, and allowed for relocations east of the Cascade Mountains, a provision of the bill made it illegal to do so west of the Cascades. In that part of the state, nuisance beavers could only be trapped and euthanized. Because the Tribe's treaty rights gave them the ability to manage wildlife and restore salmon habitat as they saw fit, they did not need permission from the state to proceed, although they did receive a letter of support from WDFW to facilitate grant applications (M. Sevigny, Tulalip Tribes Wildlife Manager, pers. comm.). Beginning in 2014, the Tulalip Beaver Project started relocating nuisance beavers to U.S. Forest Service lands in the upper Skykomish River basin (Tulalip Tribes 2023b). At that time, the Tulalip relocation effort was the only nonlethal alternative for the control and removal of nuisance beavers available to landowners in the western part of the state. Although the Tribe was able to exercise its sovereign rights to conduct this work, there was clearly a need for broader application of this process-based restoration approach. Tulalip Tribal members successfully testified as expert witnesses at the state legislature and assisted in drafting language for a bill that was signed into law, and which beginning in 2019 allowed for the relocation of beaver by non-tribal groups.

Other tribes are following in the path of the Tulalip Tribes' success. The Cowlitz Tribe in southwest Washington, for example, is working in partnership with the U.S. Forest Service to reintroduce beavers to the Gifford Pinchot National Forest. In the San Joaquin Valley of California, the Tule River Tribe is working with the Tulalip Tribes to initiate a pilot beaver reintroduction program, taking advantage of new state policies that allow for beaver relocations in support of ecological restoration (D. Collins, Tulalip Tribes Assistant Wildlife Biologist, written comm., 2023; AP 2023).

8.3.3. Enabling Conditions for Innovation

The Tulalip Tribes faced significant challenges to their plans for relocating beaver for salmon habitat enhancement, most concretely in the form of restrictive regulations and policies. However, there were several enabling conditions that allowed the Tribes to successfully launch and carry out this innovative work, particularly committed leadership, rights-holder participation and assertion of treaty rights, commitment to evidence gathering, and transparency in trade-offs.

Committed leadership. Leadership in the Tulalip Tribes Natural Resources Department was critical to the conception and execution of the beaver reintroduction project. Terry Williams, Tulalip's treaty rights commissioner, early on saw the potential for using beaver to improve long-term watershed recovery and restoration and was a determined advocate for the practice (Goldfarb 2018). Tribal leadership was also crucial for asserting treaty rights to overcome restrictive legislation, and successfully change the state law that restricted the ability of non-tribal entities to relocate beaver for restoration purposes.

Rights-holder participation and diverse perspectives. This Tribal-led project grew out of the Tulalip Tribes' deep connection to salmon and understanding of the interconnected nature of the ecosystems on which salmon and the Tulalip people depend. The conception, design, and implementation of the project reflects a blend of Tribal traditions, perspectives, and knowledge, together with Western scientific approaches applied by Tribal natural resource staff and their academic and agency partners. The role of the Tribes as a sovereign nation and treaty rights-holder, however, was instrumental in challenging and overcoming the legal barriers to initiating the project, and to opening the doors for non-tribal entities to carry out similar beaver-based habitat restoration work in the region.

Commitment to evidence gathering. The Tribes' interest in using beaver to enhance watershed restoration and salmon recovery benefited from strong engagement with scientific partners that helped make the case for relocations and identify where reintroductions would be most successful. Project partners developed a beaver potential habitat model to predict where beaver habitat could exist based on landscape variables such as stream gradient and width (Dittbrenner et al. 2018), and conducted a systematic, before-after control-impact study to evaluate the effectiveness of the reintroductions on hydrologic variables including stream temperature and groundwater recharge (Dittbrenner et al. 2022). This research documented that during the hot summer months beaver dams were effective in lowering water temperatures and reducing the potential for salmon to experience harmful temperature thresholds. The Tribes and its partners have also demonstrated a commitment to evidence gathering by integrating monitoring and metrics to evaluate the effectiveness of their actions to achieve the goals of ecological function and habitat for salmonids.

Transparency in trade-offs. Among the most interesting aspects of this work is its ability to transform what is seen as a detrimental feature in one context (i.e., nuisance beaver on private lands) into an environmental benefit in another setting (i.e., agents of process-based restoration on public lands).

This Tribal-led initiative demonstrates how applying diverse perspectives and knowledge systems, coupled with re-imagining a perceived environmental nuisance as a solution, could overcome overly restrictive policies and open a pathway for the broader application and adoption of a novel restoration approach.

8.4. Novel Fire Protection in the Tasmanian Wilderness

The Tasmanian Wilderness World Heritage Area is one of the largest remaining temperate wilderness areas in the southern hemisphere. As one of only two areas globally listed for seven of the ten criteria for World Heritage listing, it is recognized for both natural and cultural heritage of Outstanding Universal Value (DPIPWE 2021a). One of the outstanding values of the region is its high concentration of ancient lineages of plants and invertebrates endemic to the island of Tasmania (hereafter paleoendemics)(Bowman et al. 2021). Paleoendemic plants such as conifers from the genus *Athrotaxis* (Cupressaceae) and the winter deciduous Nothofagus gunnii form distinct, highly fire-sensitive plant communities that contribute to the iconic beauty of the region.

These paleoendemic plant communities typically occur in fire-protected locations of the coolest and wettest environments of Tasmania. However, a number of lines of evidence indicate these fire refugia are increasingly threatened by wildfire, potentially associated with changes in climate: conifer tree rings confirm warming summer temperatures since the 1950s, records demonstrate that lightning-ignited fires have increased in number and extent since the 1990s, and down-scaled climate projections point to more frequent fire weather this century (Bowman et al. 2021). Indeed, in January 2016 a series of unprecedented wildfires burned through fire refugia, devastating *Athrotaxis*

Pencil pine (Athrotaxis cupressoides) *and other paleoendemic Tasmanian species are fire intolerant, but their historically cool and wet habitats increasingly are subject to severe, climate-change-fueled wildfires. Photo: Cradle Mountain-Lake St. Clair National Park. Credit: Shane Pedersen/Alamy.*

forests as well as extensive areas of sphagnum peatlands. Attribution studies showed that the warmth and dryness of the drought conditions preceding and promoting the intensity of these fires could be attributed to the forcing of anthropogenic climate change (Bowman et al. 2021).

8.4.1. Innovative Fire Management

As a consequence of these fires, the Tasmanian government led the establishment of innovative fire management research and planning for the Tasmanian Wilderness World Heritage Area (e.g., Press 2016; DPIPWE 2020, 2021b). This plan incorporated prioritization in mapped fire-sensitive areas of standard fire management actions such as surveillance of ignitions, planned burning, and rapid attack of uncontrolled fires using multiple approaches. Importantly, plans incorporated innovative methods, including caching of specialist firefighting equipment in remote areas and the installation of irrigation systems in the wilderness areas to protect paleoendemic plant communities from approaching wildfire. Indeed, the integrated fire management approach proved highly successful in preventing fire spread into any paleoendemic plant communities during the extensive fires that followed in 2019. This included sprinkler systems extinguishing the Gell River fire just before it reached prioritized sensitive vegetation at Lake Rhona.

The unprecedented fires of 2016 are an example of how a system shock can serve as a stimulus for innovation and lead to the development of novel adaptation approaches (see Section 4.4.1). In Australia, a wilderness area is defined as a self-perpetuating area that remains largely undisturbed by modern human development; hence, the need for adaptation interventions to ameliorate increasing impacts of fire was at odds with the core wilderness values of the region, and reduced the impetus for innovation. Indeed, this conundrum led to federal- and state-led inquiries and global media attention about acceptable responses to the impacts of climate change on this wilderness World Heritage area. Further, as a large, remote, and inaccessible area, human ability to limit or suppress fire is very constrained and extremely expensive; the cost of fighting the 2016 fires alone was estimated at nearly 35 million U.S. dollars (Bowman et al. 2021). Innovation potential was thus constrained by costs and biophysical limitations to potential responses.

8.4.2. Enabling Conditions for Innovation

Fortunately, these barriers were outweighed by a series of important enablers that ultimately resulted in the implementation of effective fire suppression strategies. Some of the most notable of these were related to high levels of knowledge, benefits clearly outweighing risks, and unusually high levels of resources.

Novel insights. The 2016 fires brought home the stark reality that the long-unburned, fire-sensitive forests of Tasmania were vulnerable to extreme wildfire. At the same time, clear projections were available that showed fires would worsen under climate change (recognized also by the International Union for Conservation of Nature) and that the refugial niches of Tasmanian endemics were likely to shrink dramatically. This new knowledge, grounded in both tangible events and rigorous scientific predictions, was a timely enabler that triggered re-evaluation of fire management in the region and development of new approaches (Bowman et al. 2021, DPIPWE 2021a).

Open to taking risks and transparency in trade-offs. The social-political incentives to ameliorate future impacts of fire in the wilderness area were very high, due to the national and global recognition of the conservation values of the area and its high aesthetic and tourism values. This meant that there were clear reputational and economic risks in doing nothing—risks that were determined to be greater than those involved in establishing and implementing an innovative climate adaptation action plan.

Sufficient resources. Another significant enabler for innovation in climate adaptation management was the World Heritage listing itself. This designation provides the highest level of resourcing available in Australia for nature conservation, and enabled development and implementation of multifaceted innovations in fire management (Bowman et al. 2021).

This case study highlights how a severe threat to highly valued systems—the Tasmanian wilderness and its paleoendemic species—created the social conditions that enabled the adoption of bold new adaptation approaches and increased levels of investments.

Yukon Flats National Wildlife Refuge is an important repository of carbon-rich yedoma permafrost. Thawing yedoma, accelerated by more frequent and intense wildfires, could release massive amounts of climate-altering carbon dioxide and methane gases into the atmosphere. Credit: Ted Heuer/USFWS.

8.5. Protecting Carbon-rich Permafrost in the Yukon

Fire regimes across Alaska and Canada are intensifying, with the vast boreal forest forecast to shift from a carbon sink to a carbon source as large fires consume biomass. Beyond the emissions released in each fire, permafrost can become vulnerable to thaw when thick, insulative duff layers burn. Yedoma is a type of carbon-rich permafrost that originated in the Pleistocene, and yedoma thaw has the potential to significantly amplify global climate change. Indeed, thawing yedoma can release up to ten times more greenhouse gases than other, sandier types of permafrost.

Changing fire management practices to safeguard permafrost carbon stores in boreal Alaska is an innovative adaptation strategy initiated by the manager of the Yukon Flats National Wildlife Refuge (NWR). The project aims to limit the scope and scale of fires that are directly over yedoma-rich soil within the refuge with the goal to, at least temporarily, reduce the amount of warming and thawing that releases carbon out of those soils. Fire suppression as a tool is not new. What is innovative is having the fire community respond to permafrost as a valued resource at risk, especially in a region where logistical challenges have focused active fire management almost exclusively on built structures.

8.5.1. From Conception to On-the-Ground Application

This project is currently in the implementation phase of the innovation lifecycle, after moving through discovery and ideation and screening and refinement. Problem exploration and ideation crystalized in an April 2021 fire management workshop hosted by the refuge to explore the impacts of and management options for adapting to changes in the fire regime. Subject matter experts, including Indigenous partners from the Yukon Flats region, came together to talk about these issues with refuge staff. In this workshop, the idea of creating a “Pleistocene refuge” to protect yedoma was said out loud, somewhat in jest but also with some seriousness. Scientists from the Woodwell Climate Research Center reinforced the plausibility of the idea, offering evidence that the cost of fire management to protect yedoma carbon compared favorably when evaluated against the cost of damages that would be caused by the release of the carbon as well as the cost of other currently available greenhouse gas mitigation technologies. After the workshop, continued idea development and refinement came through conversations with permafrost experts and staff at the Bureau of Land Management (BLM) Alaska Fire Service. The U.S. Fish and Wildlife Service worked with experts to produce better maps of the 3.5 million acres of yedoma within the 8.6-million-acre Yukon Flats NWR. In response to concerns about firefighter safety, the Alaska Fire Service modeled the response times for transporting an injured firefighter via helicopter. This information was used to identify fire suppression areas that met minimum safety requirements, ultimately focusing on eight areas totaling 1.8 million acres. The entire state of Alaska, including wildlife refuges, is covered by fire management plans that dictate initial attack strategies, and these plans provided the vehicle for formalizing the new yedoma fire protection goals. The fire management plan for these eight yedoma areas were adjusted so that, rather than just monitoring a fire, the revised plan calls for suppressing the fire when threats to life and property do not take precedence and there is high confidence that the fire can be fully contained in 72 hours.

Implementation of this new approach to yedoma protection began with an official change to the fire management plan that was finalized before the 2023 fire season. Although now operational, the plan is still in the early stages of application, and has not yet been thoroughly tested given that 2023 was a very wet year. Indeed, in 2023 only ten percent of the normal acreage burned and there was a shorter-than-average fire season length. In all, nine fires burned 6,192 acres in the refuge. One fire burned about two acres in one of the newly designated yedoma protection areas in late August, but this fire was not detected until after season-ending rains. When fires happen, long-term monitoring is planned to assess success. The collaborative process of changing the fire management plan moved the project into early stages of diffusion and adoption since managers in other agencies and other places now know about the effort and are interested in the outcome.

8.5.2. Barriers to Adoption

Many of the barriers to realizing these changes in yedoma fire management were associated with uncertainty. As the key decision-maker, the refuge manager had to overcome self-doubt and fears about taking a risk that could disappoint their staff, superiors, people living in the Yukon Flats, and those providing fire suppression services. There was also uncertainty about getting others on board. Fire management has a long history of suppression that required a cultural shift to recognize fire as a natural component of the ecosystem. Returning to a suppression approach felt like going backwards for some people. There was also the possibility that actions to suppress fire today may make the system more flammable in the future. People weren’t on the same page in the beginning. Firefighter safety during initial attack was an immediate short-term risk, and the effects of smoke exposure to firefighters and residents of the area was also considered. Getting people to understand why this was important and to accept that we can try to change how we are doing business was one of the biggest barriers. Other barriers were technical and related to project design. Creating an experimental design and agreeing about what metrics could be used to measure success was and continues to be a challenge. The scale of the landscape and issues with fighting fires in remote areas created feasibility barriers around cost and the staffing required. Alaska Fire Service wondered how many additional resources would be needed to implement the strategy because of their assigned role as a service provider for fire suppression to the federal agencies like the Fish and Wildlife Service.

8.5.3. Enabling Conditions for Innovation

Ultimately, these barriers did not stop the initiative from moving forward. There were clear enabling conditions that allowed the project to be implemented. Specifically, this project was possible because of leadership, clear roles, institutionalized iterative planning, inclusive convening venues, and diverse expertise and perspectives.

Committed leaders and culture of trust. The leadership offered by the refuge manager and others was critically important. Several people involved were willing to clearly articulate concerns, rather than offer solutions, and then to really listen, consider issues and perspectives, and address them, allowing the project to move forward. Even before the refuge manager was in their current position, the regional fire ecologist and others were willing to question the status quo and make space for dialogue. They kick-started real two-way communication about the problem and solutions. Relationships and trust were built among fire managers, residents, and researchers over several years. After a 2019 presentation from the Woodwell Climate Research Center, the refuge manager slowly and methodically used their formal and informal authority to shine a light on the challenge and marshal the facts and the arguments from all in a conversational way. The refuge manager was trained by the National Conservation Leadership Institute, which gave him a framework and tools to treat the problem of changing boreal fire regimes as an adaptive challenge and not just a technical problem. Technical problems are the things that people know how to address and solving them requires standard operating procedures. Adaptive challenges are problems that people do not know how to solve and are often wrapped up with values and traditions.

Open to taking risks. The refuge manager was willing to make hard decisions in the face of uncertainty. The last revision to the fire management plan was in 2012 and identified climate change as an emerging problem that eventually might be addressed by a national policy from U.S. Fish and Wildlife Service headquarters. The refuge manager believed that such a policy was not coming anytime soon and that waiting for scientific certainty would result in no action and continued loss of permafrost and its carbon. They believed that not acting would be irresponsible and that leveraging partnerships and treating actions as experiments provided a path forward.

Clear roles. BLM's Alaska Fire Service is the suppression agency for the Yukon Flats NWR. Their goal is to provide the fire services that the manager of the jurisdictional agency is asking for. In this case, Alaska Fire Service staff having a clear understanding of their roles and responsibilities allowed them to respond to the changes the refuge manager was asking for, even if those changes were different than how things have traditionally been done.

Nimble and adaptive. Alaska's fire management planning process is designed to be iterative, so there is precedent for making adjustments to plans and suppression strategies. Every winter, land managers are queried about changes they would like to make to the fire management options for the land they manage. The process can be relatively nimble because making these annual adjustments, although involving consultation with adjacent land managers, does not require a formal and time-consuming revision of the full plan. The scope and scale of the existing plan allows these types of iterative changes with managers, and facilitates the incorporation of novel approaches and ideas.

Continuous learning and diverse perspectives. The Alaska Fire Science Consortium is a convening venue deliberately set up for engagement and learning between research and management. Research that is relevant for changing fire management plans is shared. The Alaska fire management community has annual spring and fall meetings. These meetings are strategically planned to have specific time to discuss emerging issues. The fire community in Alaska has built social networks with opportunities for real, two-way dialog and information exchange. Innovation also came from the diversity of expertise that included economists, policy scientists, physical scientists, ecologists, fire planners, and others because fire touches many people in different ways.

This case study illustrates how long-term investments in relationship building, planning processes, and learning networks can pay off by creating the trust among key stakeholders that allowed a realignment of existing fire management strategies and adaptation approaches.

Innovation, by nature, involves thinking and doing things differently. Photo: Firefighters in 2021 wrapping Sequoia National Park's General Sherman Tree—the largest tree on Earth by volume—to help protect it from fire burning into old cavities or fire scars. Photo: Elizabeth Wu/NPS.

Chapter 9. Rising to the Innovation Imperative

As our case is new, so we must think anew and act anew. —Abraham Lincoln

Climate change is rapidly taking species, ecosystems, and humanity into a world unlike past experience. Biodiversity, ecosystem services, and entire societies are increasingly threatened by climate extremes, novel environmental and ecological realizations, catastrophic events, and complex and poorly understood interactions. Although existing conservation practices, developed and refined over decades, centuries, and even millennia, remain necessary for addressing climate-change impacts, they are insufficient to meet rapidly emerging novel challenges. Many conventional approaches will become obsolete or require modification as climate change continues. As a result, successfully adapting to climate change will require rapid development and application of innovative practices, approaches, and policies.

9.1. Adopting an Innovation Mindset, Creating an Innovation Culture

Successful innovation is rarely the result of solo practitioners, no matter how brilliant, working in isolation. Rather, innovation is best accomplished by groups or teams with diverse and multidisciplinary expertise and perspectives. Individuals and teams operate within a broader institutional context, and organizational leadership, policies, and culture can either nurture or impede innovation. Indeed, an important driver of innovation is the interplay between top-down strategic priorities and investments within an organization and the ability of organizations to encourage and take advantage of bottom-up expertise, insights, and opportunities (Section 4.4.3). Innovation is best supported by a dynamic interplay between creative and insightful individuals and supportive institutions that nurture and promote creativity and innovation. This interchange can be characterized as the adoption and internalization of an innovation mindset within individuals and the creation and maintenance of an innovation culture within institutions (Figure 9.1).

Innovation mindsets are enabled, empowered, and motivated by innovation cultures, and in turn innovation cultures are fostered and maintained by the commitments and actions of individuals at all organizational levels, from junior staff to senior executives. Similarly, all organizations involved in climate adaptation, whether local or global, small or large, research or applied, can develop innovation cultures.

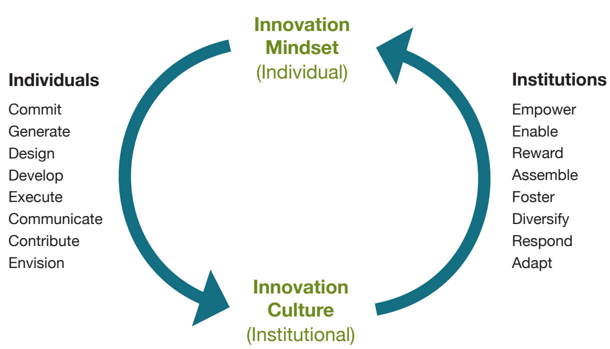


Figure 9.1. The mutually reinforcing nature of innovation mindsets among individuals and innovation culture within institutions.

Within an institution, senior leaders have a special role to play in creating an innovation culture by crafting a strategic vision that embraces innovation and establishing policies and procedures that enable creativity and risk-taking and that empower and reward innovators. At other staff levels, individuals can contribute by generating new ideas, and engaging in the design, development, testing, and implementation of novel solutions in collaboration and communication with others. Individuals can contribute to promoting an innovation culture in other ways as well, from assisting and providing feedback to dismantling or lowering key barriers. Collectively, individual actions can contribute to development and maintenance of an institutional culture of innovation. Within such a culture, the organization empowers new ideas, enables development and implementation of innovations, assembles a workforce of diverse and complementary perspectives, encourages partnerships, and fosters communication and collaboration within the workforce and with partners. Ideally, the institution is capable of nimbly responding to changing needs, internally and externally, and adapting to emerging circumstances. The reciprocal interactions between individuals and institutions depicted in Figure 9.1 provide the foundation for development and sustenance of innovation mindsets and cultures.

9.1.1. Features of an Innovation Mindset

Adopting an innovation mindset is supported by a recognition of the need and urgency for innovation (Chapter 2), an understanding of the fundamental properties of innovation (Chapter 4), including potential barriers (Chapter 5) and conditions that can enable and foster innovation (Chapter 6). This is facilitated by a familiarity with the overall innovation lifecycle (Chapter 3), including where and how individuals and teams fit into the innovation process. Because of inherent apprehension about risks associated with trying something new, a clear and fact-based understanding of risks (Chapter 7), along with transparency in trade-offs, is also important. Although risk management may seem more of a concern for leadership, individuals at all levels have a role to play by identifying different types of potential risks, including the risks of inaction, and by maintaining clear and open communication within and among participating organizations and with stakeholders and rights-holders. Perhaps the most important properties of an innovation mindset, however, are a commitment to continuous reflection, an openness to questioning current assumptions and practices, a willingness to think creatively about how to confront emerging challenges—and how to contribute to creating an innovation culture.

9.1.2. Features of an Innovation Culture

Features of an innovation culture comprise many of the same attributes as those of an innovation mindset, but at the organizational or institutional level. Ideally, the entire climate adaptation community, across the spectrum of participating organizations and other entities, will benefit from a shared, boundary-spanning culture of innovation. Leadership within individual organizations, disciplines, and professions should acknowledge the need and urgency for innovation (Chapter 2), understand its fundamental properties (Chapters 3 and 4), and work to minimize relevant barriers (Chapter 5) and support enabling conditions (Chapter 6) within and among their organizations. They should also seek to understand and manage risks (Chapter 7), both to their own organizations and to the adaptation enterprise as a whole. Failure of an innovation at one organization may have consequences for the entire adaptation community. At the same time, different organizations have differing risk tolerances and sensitivities, and varying capacities for risk management. Creative partnerships among institutions with shared goals can lead to more effective division of roles and responsibilities and management of risks. Overall, organizations and communities of practice must maintain a continuing commitment to fostering cultures of innovation.

Innovation, at the individual and institutional level, must be more than a buzzword, slogan, or cliché. In the context of this guide, promoting innovation entails a commitment to ***processes*** by which ***novel solutions*** are developed and applied that contribute ***value*** to the climate adaptation enterprise (Section 4.1). And in assessing risk, individuals and organizations should balance risks of specific innovations against the consequences of inaction or failure of existing approaches. Finally, because innovation in contemporary culture may connote “disruption,” we emphasize the development and application of innovations within the context of intentional and participatory adaptation planning processes. In some circumstances, innovations will be stand-alone products or initiatives, but they will need to develop appropriate niches within the developing adaptation ecosystem. In many cases, elements of the innovation lifecycle can be embedded into and integrated with existing planning and management processes, and many innovations will include, complement, or repurpose existing practices.

9.2. Embedding Innovation in Conservation Policy and Practice

Biodiversity conservation and natural resource management encompasses a wide array of individual roles and responsibilities, and relevant lessons and advice for embedding innovation in policy and practice are similarly varied. We distill key insights from this guide that are particularly pertinent to the work of three key sectors: *policymakers and funders; researchers and educators;* and *natural resource managers and conservation practitioners.* We acknowledge these three broad categories are an oversimplification of a complex landscape, and many individuals have responsibilities that span these and other categories. Nonetheless, there are different steps that those in these sectors can take to accelerate and expedite the innovation process in the service of effective biodiversity and ecosystem adaptation.

9.2.1. Policymakers and Funders

Policymakers, institutional leaders, and funders in both the public and private sectors have a particularly important role to play in promoting innovation, especially through establishing a conducive environment and culture for innovation. Among the actions relevant for this sector is institutionalizing processes for leaders and supervisors to be accountable for building a culture of trust, exploration, and ideation within their organization, and for empowering novel and creative thinking at all staff levels (Sections 6.1.1 and 6.4.1). Managers and planners should also be encouraged to take acceptable risks by adopting policies that allow for and encourage climate adaptation generally, including novel or experimental approaches, and that promote risk-informed decision-making (Section 6.1.3). Institutional leaders should also promote outcome-focused planning for conservation activities by developing policies that require and provide adequate support for evidence-building monitoring and evaluation plans (Sections 6.1.4, 6.3.3, 6.3.4, and 6.4.1). Policymakers and leaders should also promote the meaningful participation of a diverse and inclusive range of interested and affected groups in climate adaptation research, planning, and management (Section 6.2.1), and create and fund climate adaptation training programs that incentivize and foster broad, systems-level thinking (Section 6.3.3).

9.2.2. Researchers and Educators

The research and education sector has a key role to play in promoting innovation in adaptation as well. Knowledge and learning are essential to the innovation process, particularly in understanding climate-related risks to species and ecosystems, unraveling the complexities of socio-ecological systems and their functioning, and developing new insights into both problem formulation and novel adaptation solutions. To help promote innovation in this arena, researchers and educators should develop and support more transdisciplinary, climate-focused, and solutions-oriented programs and curricula at undergraduate and graduate levels to foster critical, collaborative, and systems-thinking skills in the next generation of professionals (Sections 6.3.3 and 6.4.2). There is also a need to recognize, reflect, and incorporate diverse knowledge systems into climate adaptation research and workforce training (Sections 6.3.1 and 6.3.2). Finally, it would be helpful to develop and pursue research focused on the process of innovation in climate adaptation, aimed at refining guidelines and best practices for effective innovation, development of innovation mindsets, and maintaining innovation cultures.

9.2.3. Resource Managers and Conservation Practitioners

Ultimately, innovative adaptation practices must be put into practice. Natural resource managers and other conservation practitioners are involved in a wide range of planning and management activities, which increasingly should be incorporating climate considerations and adopting adaptation principles. There is, however, a need for innovation and creative thinking to be embedded in the full spectrum of planning, management, and monitoring activities, with a particular focus on understanding the changing nature of risks to the resources under management and a periodic reexamination of assumptions underlying management strategies and tactics. This should include embedding risk-informed planning in decision-making, including the risks from business-as-usual practices, in order to facilitate development of new approaches that fall within acceptable risk profiles (Section 6.1.3). There is also a need to develop and promulgate participatory practices that encourage the incorporation of diverse and multidisciplinary perspectives and Indigenous knowledge in adaptation planning, including through the meaningful participation of underrepresented and marginalized groups. Planners and managers should also strive to achieve transparency in trade-offs among potential adaptation options, both novel and conventional, by establishing clear and holistic criteria that include perspectives of rights-holders and stakeholders in evaluating adaptation and management strategies (Section 6.2.2). Finally, there is a need to monitor, document, communicate, and share knowledge and experiences of innovative adaptation efforts both within and beyond the organization (Section 6.3.4).

9.3. Rising to the Innovation Imperative

Given accelerating impacts of climatic change on the natural world, there is an urgent need for bolder and more innovative adaptation responses. This guide offers an exploration of the role of innovation in climate adaptation, particularly for biodiversity and ecosystem conservation, and how this can be achieved. Through an in-depth review of the nature of innovation, processes for its generation and implementation, barriers to innovation, and enabling conditions for overcoming those hurdles, the guide provides a road map for conservationists to adopt an innovation mindset and for institutions to establish an innovation culture. The following distillation of concepts and lessons from throughout this guide is intended to inspire the conservation and natural resource management community in rising to the innovation imperative.

- **Examine assumptions.** Assumptions should be routinely and regularly questioned, whether they concern the nature of the problem, the array of available management options, or the desired conservation and adaptation outcomes.
- **Shift perspectives.** Innovative solutions often come from redefining a problem, examining it in an unconventional way, or applying new information and novel insights.
- **Look at the whole system.** Understanding, and often resetting or broadening the boundaries of a system or problem can yield novel insights and suggest new pathways and solutions.
- **Embrace diversity in all its dimensions.** Diversity of expertise, disciplines, stakeholders, communities, cultures, and knowledge systems can help redefine problems, clarify shared and contrasting values, and reveal new opportunities.
- **Be collaborative.** Partnerships and collaborations are key to bringing suitable and relevant capacity, perspective, and expertise into play to creatively solve challenging problems.
- **Learn from failure.** Having the freedom to fail is key to successful innovation, and failure should be viewed, and embraced, as an opportunity for continual and iterative learning.
- **Be experimental.** Experimentation, including testing, evaluation, and refinement, provides a systematic method for developing, implementing, and assessing novel solutions.
- **Put risks in perspective.** Don't let a general aversion to risk derail promising innovations; risks of any particular adaptation action should be weighed against the consequences of inaction.
- **Share what gets learned.** The diffusion and adoption of innovative adaptations depends on sharing ideas, experiences, and data, for both successes and failures.

Innovation, by nature, involves doing things differently. Yet changing existing practices and business processes can be daunting for both individuals and organizations. Addressing the intertwined climate and biodiversity crises, however, demands more ambition and innovation in the practice of climate adaptation. As the case studies in Chapter 8 illustrate, adopting innovative adaptation approaches is not only possible, but already is underway in a range of systems and across many organizations and agencies. It is our hope that by exploring the concepts, conditions, and techniques for fostering creativity and innovation, this guide will enable and inspire the biodiversity conservation and natural resource management community to dramatically scale up its ambitions and capacity to carry out innovative and effective climate adaptation.

Why Innovation (a haiku)

Insufficiencies
Require we innovate
This has to happen

Appendix A. Enabling Conditions for Innovation: Key Diagnostic Questions

Institutional Culture

Committed Leaders and Culture of Trust

Committed leadership that supports independent thinking and creative approaches; trust among institutional leaders and staff, and across teams.

- Do institutional leaders at various levels understand the imperative for adaptation and innovation? Is a commitment to innovation embodied in the organization's vision, processes, and/or resource allocations?
- Assuming a commitment to innovation, does the institution take a top-down or bottom-up approach to innovation, or some combination of the two?
- Do institutional leaders foster and support creative thinking and approaches? Do individuals and teams feel empowered to experiment and try new things, and trust that supervisors give them the freedom to learn from failure?
- Is there a high level of trust in institutional leaders, and among and across teams, or are there steps needed to build/rebuild trust?

Nimble and Adaptive

Processes for continuous learning and adjustment (not just following established rules, traditional tactics, and existing goals); ready and responsive to surprises.

- Are staff at various levels empowered to adjust program and project design and delivery based on changing conditions or on emerging evidence of project success, underperformance, or failure?
- Does the institution have formal mechanisms or incentives in place for encouraging adaptive behaviors?
- Does the institution have flexibility in the allocation of internal assets (personnel, financial, material) to support promising initiatives and novel work?
- Does the institution have a culture of partnership and collaboration that can allow it to be nimble in addressing changing needs and taking advantage of emerging opportunities?

Open to Taking Risks

Overcome inherent aversion to taking risks; procedures to assess risk (including the risk of inaction) but still incentivize innovation and encourage acceptable levels of risk-taking.

- Does the institution have business practices or cultural norms that offer incentives for individuals or teams to take risks, track results, and learn from both successes and failures?
- Does the institution have effective risk assessment and management practices designed to avoid activities that carry unacceptable or intolerable risks, but not stifle the development of novel practices with acceptable risk profiles?

Outcome Focused

Focus on achieving outcomes rather than simply adhering to business-as-usual actions and approaches; willingness to articulate and adopt future-oriented, rather than retrospective, goals and outcomes.

- Are existing institutional goals likely to remain robust in the face of projected climate change or will modifications or refinements be needed to make them more climate-informed?
- Do existing institutional metrics and reward structures encourage carrying out business-as-usual actions and approaches, or allow for rethinking actions and strategies to better achieve desired adaptation outcomes and impacts?
- Can the institution describe a "theory of change" for its adaptation work, including a clear articulation of the desired outcomes or impacts of those efforts?

Governance and Decision-making

Participation of Rights-holders and Stakeholders

Processes in place for meaningful participation of a diverse range of interested and affected groups—including in problem identification.

- What is the role and level of involvement of Indigenous rights-holders and community stakeholders in adaptation decisions? Are the principles of free, prior, and informed consent being applied and are there opportunities for Indigenous and community leaders to meaningfully engage in framing of problems and crafting of possible solutions?
- Recognizing that one-size-fits-all approaches rarely work in local social-ecological contexts, is the role/process for involving rights-holders and stakeholders specifically defined?
- Are there opportunities to recognize and support the participation of rights-holders and stakeholders in the adaptation (and innovation) process (e.g., compensating for time, travel, etc.).

Transparency in Trade-offs

Processes for exploring potential outcomes of novel adaptation approaches in ways that allow for an understanding of costs, benefits, and consequences from the perspective of different values and rights-holders/stakeholders.

- Is there a clear process in place to explore and confront possible trade-offs among innovations, and clear criteria for evaluating potential innovations and alternative strategies?
- Are all relevant parties, including rights-holders and stakeholders, participants in the process of characterizing and evaluating trade-offs from the perspective of shared as well as divergent values?
- Are novel adaptation approaches available that might overcome historical trade-offs and conflicts and create new opportunities for win-win solutions?

Knowledge and Learning

Novel Insights

Invests in generating new information and deeper understanding that can lead to novel insights into the nature of the problem and into pathways capable of addressing adaptation challenges.

- What processes and investments are in place that can allow for the generation of new knowledge that might enable new perspectives on understanding the problem at hand?

- Is the institution making investments or engaged in collaborations designed to advance fundamental understanding of the system of interest and generate novel insights into the nature of the problem and possible adaptation responses?
- How are new and emerging technologies being adopted and deployed to generate new knowledge and insights into system condition and function and climate-related risks?

Diverse Perspectives

Processes that consider diverse perspectives and varied forms of knowledge (e.g., Western science and Indigenous knowledges) and encourage cross-disciplinary thinking that supports, rewards, and encourages knowledge co-creation.

- Does the institution have leadership representative of diverse perspectives and backgrounds (culturally, socioeconomically, etc.) to guide the engagement of diverse rights-holders and stakeholders?
- Does the institution have processes in place, either internally or through collaborative partnerships, to access cross-disciplinary, multi-perspective thinking, and for considering and incorporating diverse forms of knowledge and worldviews, including from traditions other than Western science?
- Are diverse forms of knowledge and knowledge systems evaluated within the appropriate rules and standards of validation and verification of its production? Is there a process to support the autonomy and data sovereignty of diverse knowledge systems?

Continuous Learning

Processes for effective learning and knowledge management to support shared learning and knowledge exchange within and across institutions and networks.

- Are the institution and its leaders committed to continuous adaptive learning and improvement, and to incorporating new ideas, observations, and practices as more is learned? Do they accept failure as a learning opportunity?
- Does the institution or program have mechanisms in place to gather evidence, which may include using experimental approaches and controls when appropriate and warranted?
- Does the institution promote documentation, communication, and sharing of knowledge across different programs within the organization? Does the institution (or individuals) participate in external learning networks to support knowledge exchange across institutions?

Commitment to Evidence Gathering

Mechanisms and support for relevant and effective monitoring and evaluation, including processes for determining what needs to be monitored, how, by what metrics, and by whom.

- Have time and effort been invested in developing an effective monitoring and evaluation plan (e.g., that defines successful adaptation outcomes, articulates a "theory of change," and identifies metrics to measure near- and longer-term outcomes)?
- Have adequate resources (funding, time, technical capacity) been secured either directly or via partnerships to support long-term evidence gathering?
- Is there a commitment to documenting and sharing evidence regardless of whether it demonstrates success, need for adjustments, or failure?

Organizational Capacity

Sufficient Resources

Sufficient time to allow for exploration, ideation, and experimentation and avoid the pressure to deploy only the most expeditious, business-as-usual approaches; sufficient funding and material resources to support the creative work of staff and partners, including those historically excluded from such processes.

- Are there processes or incentives in place that provide individuals and teams with time to explore new ideas or pursue side projects that might lead to innovative solutions?
- Are there processes in place to allocate resources to individuals and teams who are in a position to generate innovation or creative application of established techniques and approaches?
- Are processes in place to ensure that new resources can foster new and innovative approaches, not just augment traditional work and approaches?

Appropriate Expertise

Availability of both specialized expertise as well as staff and partners with varied perspectives, knowledge systems, and expertise; process to support recruitment, retention, and support of diverse leadership, staff, and partners.

- Is the organization open to periodically re-evaluating the skills and competencies of its staff with respect to emerging challenges, and seeking staff in new disciplines and/or nontraditional fields when hiring?
- Are processes in place to ensure that the organization can recruit and retain high-performing and diverse talent interested in exploring novel, outcome-based approaches to emerging adaptation challenges?
- Is the organization positioned to effectively engage outside expertise through partnerships and collaborations, including through sharing of resources and credit?

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