Preparing for and managing change: climate adaptation for biodiversity and ecosystems

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The emerging field of climate-change adaptation has experienced a dramatic increase in attention as the impacts of climate change on biodiversity and ecosystems have become more evident. Preparing for and addressing these changes are now prominent themes in conservation and natural resource policy and practice. Adaptation increasingly is viewed as a way of managing change, rather than just maintaining existing conditions. There is also increasing recognition of the need not only to adjust management strategies in light of climate shifts, but to reassess and, as needed, modify underlying conservation goals. Major advances in the development of climate-adaptation principles, strategies, and planning processes have occurred over the past few years, although implementation of adaptation plans continues to lag. With ecosystems expected to undergo continuing climate-mediated changes for years to come, adaptation can best be thought of as an ongoing process, rather than as a fixed endpoint.

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Climate-change adaptation has been discussed in the scientific community for nearly three decades, but over much of that time policy makers and climate activists largely regarded it as a taboo subject out of concern it would divert attention from addressing the underlying causes of climate change (Pielke *et al.* 2007). It has become increasingly clear that no matter how vigorously greenhouse-gas emissions are reduced, major shifts in climate will occur over at least the next century, necessitating serious action on adaptation in addition to climate mitigation (NRC 2010). Consequently, in recent years the topic of climate adaptation has received greater attention and has become an important theme in biodiversity conservation and natural resource policy and management.

In a nutshell:

- Climate *adaptation* focuses on addressing the impacts of climate change on natural and human systems, and is an essential complement to climate *mitigation*, which focuses on atmospheric greenhouse-gas concentrations
- Conservation and natural resource managers and policy makers are increasingly incorporating climate considerations into their planning and management, taking advantage of an emerging body of adaptation principles, strategies, and planning processes
- Given directional shifts in many climatic variables, adaptation efforts will need to emphasize managing for inevitable ecological changes, not just for the persistence of existing conditions
- Depending on the rate, magnitude, and character of future climatic change, even the most aggressive adaptation actions may be unable to prevent losses of biodiversity or serious degradation of ecosystems and their services

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The increased focus on adaptation can be tracked through growth in media coverage (Moser 2009), scientific literature (Glick *et al.* 2011a), and government activities (Bierbaum *et al.* 2013). Indicative of this heightened attention is a 2009 Presidential Executive Order (EO 13514) requiring all federal agencies to develop and implement adaptation plans; the establishment of a federal interagency climate adaptation task force; the release of a national fish, wildlife, and plants climate adaptation strategy; the incorporation of climate change into state wildlife action plans; and the development of adaptation plans by states, cities, and Native American tribes.

Through geological time, climatic shifts have exerted a powerful influence on biotic evolution and the development of ecosystem structure and function. The current pace of climate change, coupled with other anthropogenic stresses, such as habitat loss and fragmentation, invasive species, and altered ecological processes, is expected to exceed the innate capacity of many species and ecosystems to adjust to and accommodate such changes. The rapid transitions in climate currently underway are already affecting species and ecosystems in varied and complex ways (Staudinger *et al.* 2013; Grimm *et al.* 2013), posing considerable challenges for biodiversity conservation and natural resource management.

These climatic changes and their attendant impacts are affecting both wild and managed systems – from nature reserves and wilderness areas, to farms and ranchland, to urban parks and suburban backyards. Adaptation efforts will be relevant to each of these landscape types and land uses, and will have implications not only for the species they harbor but also for the continued provision of ecosystem services that are of benefit to human society.

There have been major advances in the development of principles, strategies, and planning processes for biodiversity and ecosystem adaptation over the past 5 years, and these advances are the focus of this review. Which adaptation strategies and actions are appropriate in any particular place or landscape will vary, depending on such considerations as societal values, conservation goals, technical feasibility, and cost, among others. Successful adaptation, however, will depend not only on the selection and implementation of appropriate strategies but also on the rate, magnitude, and character of climatic changes, highlighting the importance of continued action and progress on climate mitigation as well as adaptation.

■ What is climate adaptation?

Climate-change adaptation is an emerging field that focuses on preparing for, coping with, and responding to the impacts of current and future climate change. More formally, climate adaptation has been defined as "initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects" (IPCC 2007a) and "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities" (IPCC 2007b). As these definitions suggest, climate adaptation focuses primarily on human responses to climate change (either active or passive), as distinct from use of the term "adaptation" in the traditional evolutionary biology sense, which focuses on genetic changes over time in response to selective pressures. Although they are different concepts, evolutionary adaptation plays an important role in climate adaptation, particularly in terms of the capacity of species and populations to naturally adjust to changing conditions through genotypic shifts or phenotypic plasticity (Hoffman and Sgrò 2011). Unless otherwise noted, however, here "adaptation" refers specifically to climate adaptation.

Effective climate adaptation stems from a structured process that considers the effects of climate change on valued resources so that appropriate management responses can be identified and implemented. Because adaptation is fundamentally about managing change, it can best be thought of as a continuing process rather than as a fixed endpoint. Actions undertaken to prepare for anticipated climate-change impacts can be referred to as proactive or anticipatory adaptation, whereas actions in response to climate-related impacts can be referred to as reactive adaptation (Adger *et al.* 2005). For example, adaptation strategies in response to increasingly severe drought and forest fires might include such anticipatory actions as prescribed burns or selective forest thinning to reduce the intensity of future fires, while reactive adaptation actions might include broadening the genetic composition of plant materials used in post-fire restoration, with the goal of establishing species or strains better suited to future climatic conditions.

Adaptation actions can be targeted at different levels of biological organization (eg species, habitats, ecosystems) and designed to benefit various attributes of natural systems, such as the components of biodiversity (eg species diversity, ecological patterns), particular ecosystem processes (eg disturbance regimes, nutrient cycles, hydrological cycles), specific ecosystem services (eg water production, carbon sequestration, coastal protection), or specific locations (eg parks, wildlife refuges, cities). Adaptation strategies focusing on different biological levels or system attributes may be mutually beneficial or might work at cross-purposes. Simply put, what is viewed as adaptive for one conservation purpose might be detrimental (or "maladaptive") for another.

Adaptation can focus on either human systems or natural systems, and "ecosystem-based adaptation" (EBA) is emerging as a framework for linking these perspectives (Vignola *et al.* 2009; Jones *et al.* 2012). Despite its ecologically oriented name, however, EBA is targeted primarily toward assisting people in adapting to climate change, as reflected in the Secretariat of the Convention on Biological Diversity's (2009) definition of EBA as "the use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people adapt to the adverse effects of climate change". An example of this concept is the role of intact ecosystems (eg mangroves, wetlands) in attenuating coastal storm surge and protecting human communities along coastlines (Kaplan *et al.* 2009). Recognition and application of EBA has been growing internationally, but the term has not yet been widely adopted in the US.

■ Managing for change, not just persistence

Ecological systems have always been dynamic, characterized by variability at annual, decadal, and longer temporal scales. Indeed, the Quaternary paleoecological record provides a striking view of the degree to which species assemblages and ecosystems are characterized by change rather than stasis (Millar and Woolfenden 1999; Williams and Jackson 2007). Nonetheless, stationarity – the idea that natural systems fluctuate within a defined and constant range of variability – has been a foundational concept in many fields of natural resource management (Milly *et al.* 2008; Keane *et al.* 2009). Directional changes in climatic variables have made clear that, in the words of Milly *et al.* (2008), "stationarity is dead". Accordingly, adaptation to climate change in the context of biodiversity conservation and natural resource management is largely about managing change (Millar *et al.*

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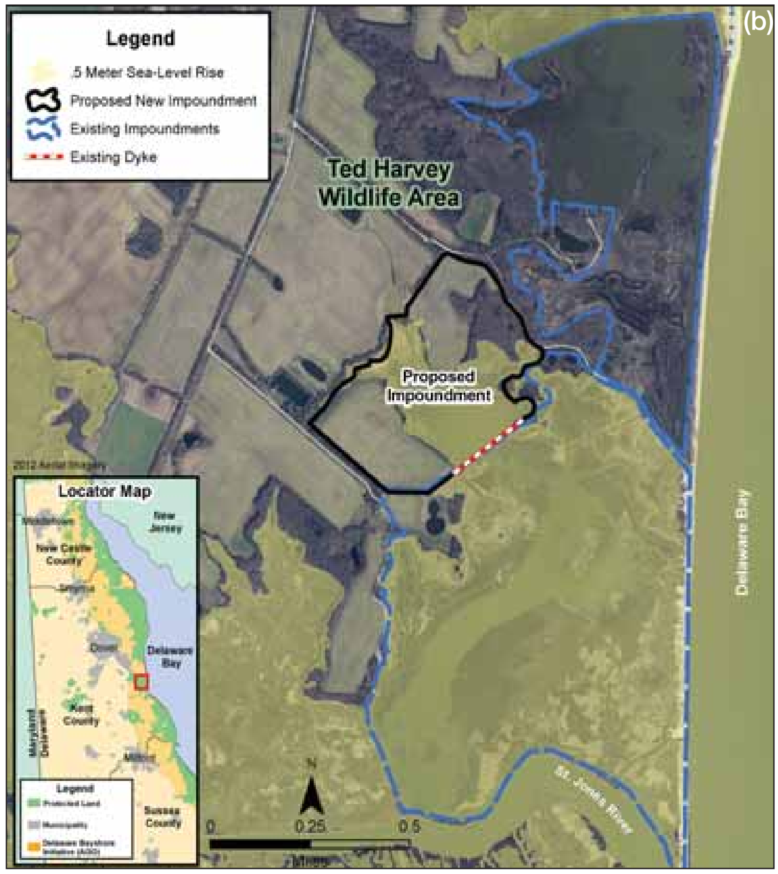

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Figure 1. *Coastal impoundments are an important freshwater and brackish-water habitat for many shorebirds and waterfowl and are increasingly vulnerable to salt water inundation from rising sea levels. (a) Since 2009, impoundments at Prime Hook National Wildlife Refuge were breached multiple times during storms, including (as above) by Hurricane Sandy in October 2012. (b) In anticipation of similar impacts to nearby state wildlife areas, the Delaware Division of Fish and Wildlife is creating new impoundments designed to accommodate rising sea levels. This adaptation effort involves shifting the location of this key coastal habitat inland and upland, as a means of sustaining the provision of ecological functions.*

2007; West *et al.* 2009; Stein and Shaw 2013).

Approaches to adaptation can range from resisting change – in order to protect high-value and climate-sensitive assets – to actively facilitating changes, so that inevitable system transitions will retain desirable ecological attributes rather than resulting in the collapse of ecosystem functions and services. One commonly used framework for adaptation responses to change consists of the continuum of resistance, resilience, and transformation (Millar *et al.* 2007; Glick *et al.* 2011b). Under this framework, resistance actions are intended to promote system persistence and maintain current conditions. Resilience has multiple meanings (eg Holling 1996; Walker *et al.* 2004; Folke 2006), but in this context it typically refers to actions designed to improve the capacity of a system to return to desired conditions following a disturbance, or to maintain some level of functionality despite being in an altered state. Transformation refers to efforts that enable or facilitate the transition of ecosystems to new functional states.

To date, most adaptation work in the biodiversity and ecosystem conservation community has focused on strategies for maintaining existing conditions. Even the widely embraced objective of "enhancing resilience" usually reflects a persistence-oriented approach by emphasizing the assumption that healthy systems will more likely rebound to their prior state following perturbations. In the past few years, however, many scientists and conservationists have begun focusing not just on resisting changes and retaining existing ecological conditions but also on the challenging task of managing or even facilitating what many now see as inevitable system transformations (Figure 1).

Reconsidering conservation goals

Effective conservation and natural resource management relies on the articulation of clear goals, which make possible the development of specific management objectives and measures of success. Goals are an expression of the desired condition of a landscape or other resource and inherently reflect human values. Such societal values can include prevention of species extinctions (as expressed in the US Endangered Species Act), maintenance of unimpaired "natural" conditions in national parks, or sustained yield of products and services from systems as varied as national forests and marine ecosystems. In a sense, goals articulate the "why" of conservation, while strategies describe the "how". However, the choice of conservation or management goals is driven as much by societal values, economic constraints, and political feasibility as by scientific knowledge.

As climatic factors continue to shift they are expected to cause realignments and alterations in both the spatial and temporal patterns of biodiversity, including the reshuffling of community composition and the emergence of "novel ecosystems" (Hobbs *et al.* 2006; Williams and Jackson 2007). Such shifts and realignments will make protecting species and ecosystems in their current locations increasingly difficult and in some cases impossible. As a result, one theme that repeatedly emerges in the adaptation literature is the need to move from a paradigm of preserving current conditions or designing restoration for "historical fidelity" to one of being open to managing for future systems that may differ in composition, structure, and/or function (Cole and Yung 2010).

Given the rate and magnitude of climate-mediated ecological changes, natural resource managers will be faced not with a choice of whether to reconsider many of our conservation and management goals, but rather when, how much, and in what ways they should change (Julius and West 2008; Glick *et al.* 2011a). In particular, goals will need to be forward-looking instead of retrospective in nature, and managers may need to expand their definitions of what constitutes a desirable ecosystem (Hobbs and Cramer 2008; Lemieux *et al.* 2011). There are, however, formidable institutional, legal, and psychological barriers to shifting current conservation paradigms and realigning goals (Jantarasami *et al.* 2010).

Among the most common suggestions for how conservation goals may need to shift is from those that focus on preserving current spatial patterns of species toward goals that focus on maintaining underlying ecological and evolutionary processes that will be important for sustaining functional ecosystems into the future (Harris *et al.* 2006; Pressey *et al.* 2007; Prober and Dunlop 2011; Groves *et al.* 2012). Species composition goals will still have relevance but may need to be expressed at different spatial or temporal scales. For example, rather than retaining the full diversity of species at specific sites (eg individual reserves), such goals may need to be restated as maintaining compositional diversity across larger landscapes. Similarly, these goals may be framed as applying to a specified time period (eg > 20 years, 20–50 years, etc). Others have suggested adopting the goal of protecting diverse geophysical settings (or "enduring features") in order to sustain current biodiversity and enable future diversification (Anderson and Ferree 2010; Beier and Brost 2010). Targeting ecosystem services of direct benefit to people has also been promoted as a primary conservation goal, to ensure the societal relevance of adaptation efforts and thereby maintain or increase support for conservation (Chan *et al.* 2006).

Summarizing the range of possible goals in light of climate change, Camacho *et al.* (2010) asked whether we want to be "curators seeking to restore and maintain resources for their historical significance; gardeners trying to maximize aesthetic or recreational values; farmers attempting to maximize economic yield; or trustees attempting to actively manage and protect wild species from harm even if that sometimes requires moving them to a more hospitable place".

Convergence on adaptation principles

A considerable body of work has spurred the recent emergence of general principles for use in biodiversity and ecosystem adaptation (eg Julius and West 2008; Heller and Zavaleta 2009; West *et al.* 2009; Hansen and Hoffman 2010; Peterson *et al.* 2011). Notable among these principles is the need for adaptation to be carried out as an intentional process, rather than assuming that existing conservation practices will suffice in the face of rapid climate change. Such an intentional approach depends on an understanding of likely impacts and vulnerabilities, with strategies and actions explicitly built on that understanding. The following five principles draw from a set of "key characteristics of climate-smart conservation" developed by an expert workgroup convened by the National Wildlife Federation (Stein *et al.* 2013; Stein *et al.* in review). While there are many other conservation best practices (eg importance of priority setting and collaborative partnerships), these principles highlight attributes that are especially important from a climate-adaptation perspective.

Embrace forward-looking goals

Conservation goals should focus on future, rather than past, climatic and ecological conditions; strategies should take a long-term view but account for near-term conservation challenges and needed transition strategies. Although the historical and paleoecological records provide important insights, past-oriented goals may no longer be achievable. Accordingly, managers will need to be open to re-evaluating and modifying goals as needed. Most resource management plans have relatively short (3- to 10-year) time horizons; effective adaptation will require that ecologists improve predictive capabilities and that managers incorporate longer term implications of climate change into current actions.

Link actions to climate impacts

Conservation strategies and actions should be designed specifically to address the impact of climate change in concert with non-climate stressors; actions should be supported by an explicit scientific rationale. In this context, climate impacts include both direct effects, such as changes in temperature or precipitation patterns, as well as indirect effects, such as rising sea level, disruptions to ecological interactions, or increased toxicity of contaminants. As climate adaptation increases in prominence, there may be a temptation to relabel existing practices and projects as adaptation. Climate adaptation actions – whether based on traditional practices or involving novel approaches – should therefore demonstrate an explicit understanding or hypothesis for how they are likely to reduce key climate-related vulnerabilities or take advantage of climate-related opportunities.

Consider the broader landscape context

On-the-ground actions should be designed in the context of broader geographic scales to account for likely shifts in species distributions, to sustain ecological processes, and to promote cross-institutional collaboration. Effective adaptation will require greater emphasis on lands and waters under varying intensities of human use (Kostyack *et al.* 2011), as well as enhanced connectivity among protected habitats (Monzón *et al.* 2011). Although the importance of planning for and implementing conservation and management strategies at a landscape scale has long been recognized, the pace of climate-induced ecological changes further underscores the imperative for doing so. To successfully work at broader landscape scales, however, it will be necessary to develop governance structures and collaborative approaches to facilitate planning and implementation across multiple jurisdictions, administrative units, and land ownerships (Pressey and Bottrill 2009).

Select strategies robust to an uncertain future

When possible, strategies and actions should provide benefits across a range of plausible future scenarios, to account for uncertainties in future climatic conditions and in the resulting ecological and human responses. Although managing in the face of uncertainty is not new to conservation, the uncertainties surrounding climate change are a major impediment for many managers to take action. Emphasizing strategies that are robust across multiple possible futures can provide managers an additional level of confidence, and increase the likelihood that adaptation plans will be implemented (Lempert *et al.* 2006; Dessai and Hulme 2007; Cross *et al.* 2012). Nonetheless, although effectiveness across multiple scenarios is desirable, specific adaptation options may often be limited to a single or smaller subset of future conditions.

Agile and informed management

Conservation planning and resource management should be flexible and dynamic enough to accommodate uncertainty, take advantage of new knowledge, and cope with rapid shifts in climatic, ecological, and socioeconomic conditions. Adaptive management is the best known approach for continuous learning and refinement of management practices, but other approaches for agile management also exist and may be appropriate (eg scenario-based planning, risk management). Putting adaptive management into practice has been challenging, however, even without the added complications that result from rapid climate change; it will be necessary to overcome a variety of technical, legal, financial, and institutional barriers to effectively employ such management approaches (Stankey *et al.* 2005; Gregory *et al.* 2006). Monitoring will be especially important for implementing such practices to track ecological changes, evaluate the efficacy of management actions, and make any needed course corrections.

Adaptation as a means to reduce vulnerability

Understanding adaptation as "initiatives and measures to reduce vulnerability" (IPCC 2007a) provides one framework for designing and evaluating possible options and approaches. Climate-change vulnerability is typically defined as consisting of three primary elements: exposure, sensitivity, and adaptive capacity (Glick *et al.* 2011b). Strategies can therefore be designed that address one or more of these vulnerability components by: reducing the degree of change experienced by the organism or system (ie exposure); reducing the sensitivity of the organism or system to those changes; or enhancing the ability of the species or system to accommodate or adjust to those changes (ie adaptive capacity; Dawson *et al.* 2011). Depending on the intended outcome, these approaches can seek to either maintain the persistence of current conditions or facilitate transitions to alternative states. Table 1 illustrates the interplay among these factors in several example adaptation efforts.

Key adaptation strategies

Recently, there has been broad convergence on various adaptation strategies, many of which build on existing conservation techniques and principles but differ in when, where, and how they are applied (Lawler 2009; Hellmann *et al.* 2011). Strategies for biodiversity and ecosystem adaptation can be grouped into three basic categories: improving current conditions; protecting and managing large landscapes; and pursuing species- and site-specific approaches (Table 2). First, several proposed approaches focus on improving the current condition of systems, with the stated goal of enhancing resilience to climate-change impacts; these strategies involve restoring ecosystem functioning and reducing other anthropogenic stresses. A second set of approaches involves protecting and managing large landscapes; these strategies include increasing the size of reserves, placing more reserves on the landscape, changing the way reserve networks are designed, and increasing connectivity among protected areas. The remainder of the strategies – generally classified as site- or species-specific – includes such approaches as managed translocation (assisted migration), supplemental watering, habitat manipulations, and ecosystem engineering.

Advances in adaptation planning

A growing number of adaptation planning approaches are being designed to help practitioners integrate climate change into conservation decisions and translate general principles and strategies into actionable recommendations (eg Peterson *et al.* 2011; Cross *et al.* 2012; Stein *et al.* in review). Even though these approaches vary considerably in terms of analytical techniques used, most can be

Table 1. Illustrative adaptation efforts

	R Hiser/Western Rivers Conservancy 	L Killam/NWF 	US Forest Service, Kaibab National Forest 	© J Jeffrey 
Adaptation action	Protect cold-water refugia	Reintroduce beavers as ecosystem engineers	Modify post-fire reforestation practices	Relocate/restore habitat and create corridor
Description	To sustain salmon runs on California's Klamath River, cold-water refuges (eg mouth of Blue Creek) have been identified and their protection is the subject of a new Thermal Refugia Protection Policy	To enhance water retention in mountain watersheds, an important factor for buffering climate impacts on an array of fish and wildlife, beavers are being reintroduced in southern Utah	To enable reforested areas to better survive under future climatic conditions, post-fire restoration efforts can use species and genetic stock drawn from wider geographic ranges and with broader climate tolerances	To sustain native Hawaiian birds by providing access to cooler habitat and a disease-free refuge, upslope forest restoration is connecting two forest reserves on the slopes of Mauna Kea, Hawaii
Key climate concerns	Warming water; decreasing summer flows	Increasing aridity; more variable stream flows	Warmer and drier conditions	Warming temperatures; upslope shift in mosquitoes carrying avian malaria
Adaptation mechanism	Reduce exposure of salmon to warming water	Enhance adaptive capacity of watersheds	Reduce sensitivity of forest community to warming	Reduce exposure of birds to warming and disease vectors
Intended outcome	Persistence-oriented	Persistence to transition	Transition-oriented	Transition-oriented

characterized as containing a number of similar steps; Figure 2 represents a generalized adaptation planning and implementation cycle that reflects several of these commonalities. This planning and implementation framework draws from, and mirrors, many standard conservation planning processes but is designed specifically to incorporate climate considerations, particularly through its emphasis on assessing climate-related vulnerabilities (step 2) and on reconsidering goals and objectives in light of those impacts and vulnerabilities (step 3). Although this cycle explicitly addresses climate considerations, the critical phase of evaluating and selecting adaptation options (step 5) necessarily considers not just technical feasibility and the likelihood of achieving desired ecological outcomes but must also take into account cost, institutional capacity, and legal/social considerations.

A particular challenge in adaptation planning is addressing the uncertainties involved in projecting future climatic changes as well as the resultant ecological impacts and human responses; these uncertainties must be considered in the individual steps of the adaptation cycle and addressed through iterative rounds of planning, implementation, and evaluation. Adaptation planners can, however, turn to many existing tools for making management decisions in light of uncertainty. Structured decision making, for instance, is a useful approach for clearly defining key issues, creating logic models, and identifying relevant strategies despite knowledge deficits and uncertainty (Runge 2011; Gregory *et al.* 2006). The coastal impoundment project profiled in Figure 1, for example, is based on the results of a formal, structured decision-making process. Other approaches include risk management (Willows and Connell 2003), robust decision making (Lempert *et al.* 2006), and scenario-based planning (Peterson *et al.* 2003). The last option, in particular, is being used to identify actions that may be relevant across multiple possible futures, which can often be considered "no regrets" or "low regrets" actions.

Table 2. Example adaptation strategies

Improve current conditions	• Reduce non-climate-related threats • Restore floodplains • Remove dams • Reduce forest-fire fuels
Protect and manage large landscapes	• Increase connectivity for species and ecological processes • Create additional protected areas • Enlarge protected areas • Protect enduring features (geophysical) • Protect climate refugia • Increase redundancy of protection provided by reserves
Species- and site-specific approaches	• Relocate organisms (managed translocation) • Manage for heat-tolerant phenotypes • Increase genetic diversity • Re-establish ecosystem engineers

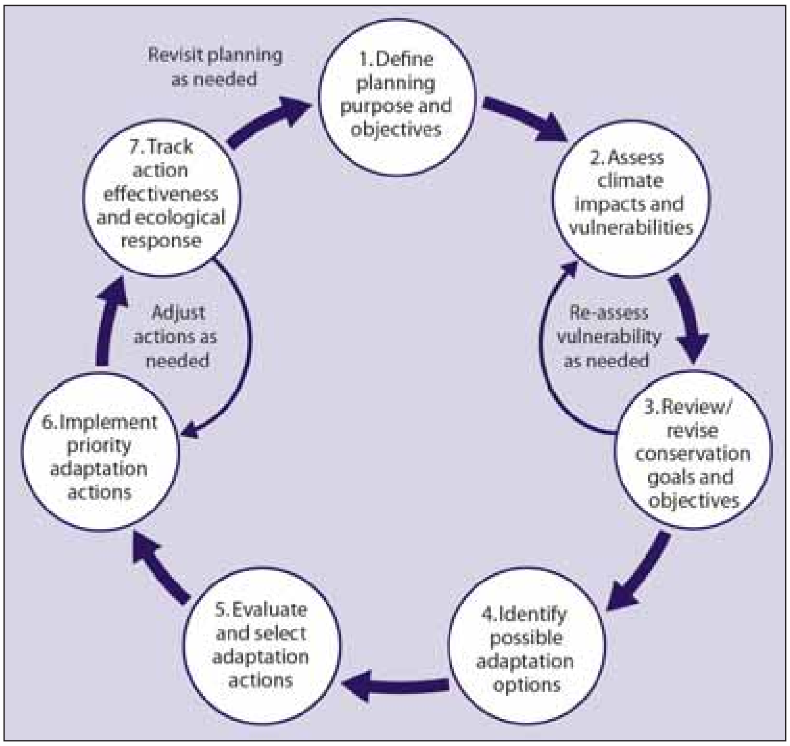

Figure 2. *Generalized framework for climate-change adaptation planning and implementation. This cycle mirrors many existing conservation planning and adaptive management approaches but includes such climate-focused elements as assessing climate-related vulnerabilities (step 2) and reconsidering conservation goals in light of those vulnerabilities (step 3). Although presented in a linear fashion, depending on specific needs, one may enter the process at various stages or emphasize different components. From Stein* et al. *(2013).*

■ Slow progress on implementation

Implementation of adaptation plans and strategies continues to lag, and overcoming barriers to their execution is one of the current challenges for climate adaptation. Moser and Eckstrom (2010) provided a diagnostic framework for identifying barriers that may impede the adaptation process, along with suggestions for overcoming these barriers. One particular impediment for many resource managers is the perceived need to focus on urgent, short-term threats rather than on longer term adaptation needs, especially in an era of severe budgetary constraints. An approach for helping reconcile this dilemma is identification of management options that have near-term benefits but are consistent with longer term adaptation needs. Another important barrier is the sense among some managers and institutions that addressing climate change is a distinct (and often unfunded) activity to be carried out in addition to their existing responsibilities. While early efforts to develop adaptation plans began as stand-alone endeavors, adaptation increasingly is being integrated into and informing existing planning and decision-making processes. Implementing climate-adaptation actions will also be highly dependent on the capacity and culture of the institutions charged with managing US lands and waters. Indeed, while the concept of adaptive capacity is often thought of in reference to the species and ecosystems that are the targets of adaptation action, the ability of institutions themselves to adjust and evolve will be key to their ability to manage for change.

■ The adaptation paradox

There are limits to adaptation, which revolve around thresholds of an ecological, economic, or technological nature (Adger *et al.* 2009). For instance, ecological or physical thresholds exist beyond which adaptation responses will be unable to prevent serious climate-change impacts (eg temperature thresholds for organisms, such as thermal stress in corals or cold-water fishes). Economic thresholds can be defined as when the costs of adaptation exceed the costs of averted impacts (ie it is more expensive to adapt than to experience the impacts). Finally, there are technological thresholds beyond which engineered or management solutions cannot avert the effects of climate change.

The rate, magnitude, and character of climatic changes will influence whether and when these limits are exceeded. For instance, a given species may be capable of accommodating a level of change that occurs gradually, through either phenotypic adjustments or adaptive evolution (Hoffman and Sgrò 2011), but may be incapable of accommodating the same degree of change if it occurs rapidly. Similarly, a species or system may have the capacity to adapt to changes in an ecologically intact setting but is unable to adjust when additional anthropogenic stresses, such as a highly fragmented landscape, are also present. Although shifts in climate have been a factor throughout evolutionary history, there now exists a unique combination of rapid rates of climatic change together with profound and pervasive human impacts on the landscape that may limit the natural adaptive capacity of many species and systems. Indeed, depending upon the rate, magnitude, and character of future climatic change, society may be unable to prevent losses of biodiversity or serious degradation of ecosystems and their services even if aggressive adaptation actions are implemented.

Global average temperature increases will likely exceed the 2°C target that scientists and policy makers had identified as a threshold for avoiding dangerous interference with the climate system (IEA 2011). Accordingly, the need to adapt to increasing climate impacts will only become more acute as higher levels of warming and associated changes occur. The central paradox is that, as higher levels of warming make the need for adaptation more imperative, these temperature increases, and the scale of attendant impacts, are likely to substantially limit the effectiveness of adaptation options. As the rate and magnitude of climatic changes increases, adaptation efforts will be tested and possibly compromised as ecological, economic, and technological thresholds are reached. This paradox highlights the importance of viewing adaptation as fundamentally about managing rather than resisting change and a complement to and not a replacement for serious action on climate mitigation.

Despite the challenges that rapid climate change poses to the nation's biodiversity and ecosystems, there is now much energy and effort underway, focused on how the emerging field of climate adaptation can make a difference for conservation and resource management. With ecosystems expected to undergo continuing climate-mediated changes for years to come, however, conservation goals and adaptation strategies will need to be revisited regularly and viewed as an ongoing process rather than a fixed endpoint. Climate change represents a uniquely 21st century conservation challenge, but biodiversity and ecosystem adaptation can draw from and build on a rich conservation tradition. Indeed, successful adaptation over the long term will likely depend on what the eminent conservationist Aldo Leopold presciently referred to more than 60 years ago as the "capacity for self renewal" (Leopold 1949).

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