1 Executive Summary

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Climate variables are key determinants of geographic distributions and biophysical characteristics of ecosystems, communities, and species. Climate *change*[1] is therefore affecting many species attributes, ecological interactions, and ecosystem processes. Because changes in the climate system will continue into the future regardless of emissions mitigation, strategies for protecting climate-sensitive ecosystems through management will be increasingly important. While there will always be uncertainties associated with the future path of climate change, the response of ecosystems to climate impacts, and the effects of management, it is both possible and essential for adaptation to proceed using the best available science.

This report provides a preliminary review of adaptation options for climate-sensitive ecosystems and resources in the United States. The term "adaptation" in this document refers to adjustments in human social systems (*e.g.*, management) in response to climate stimuli and their effects. Since management always occurs in the context of desired ecosystem conditions or natural resource management goals, it is instructive to examine particular goals and processes used by different organizations to fulfill their objectives. Such an examination allows for discussion of specific adaptation options as well as potential barriers and opportunities for implementation. Using this approach, this report presents a series of chapters on the following selected management systems: National Forests, National Parks, National Wildlife Refuges, Wild and Scenic Rivers, National Estuaries, and Marine Protected Areas. For these chapters, the authors draw on the literature, their own expert opinion, and expert workshops composed of resource management scientists and representatives of managing agencies. The information drawn from across these chapters is then analyzed to develop the key synthetic messages presented below.

Many existing best management practices for "traditional" stressors of concern have the added benefit of reducing climate change exacerbations of those stressors.
Changes in temperature, precipitation, sea level, and other climate-related factors can often exacerbate problems that are already of concern to managers. For example, increased intensity of precipitation events can further increase delivery of non-point source pollution and sediments to rivers, estuaries, and coasts. Fortunately, many management practices that exist to address such "traditional" stressors can also address climate change impacts. One such practice with multiple benefits is the construction of riparian buffer strips that (1) manage pollution loadings from agricultural lands into rivers today and (2) establish protective barriers against increases in both pollution and sediment loadings due to climate changes in the future. While multiple benefits may result from continuing with today's best practices, key adjustments in their application across space and time may be needed to ensure their continued effectiveness in light of climate change.

Seven "adaptation approaches" can be used for strategic adjustment of best management practices to maximize ecosystem resilience to climate change.

[1] Climate change refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that in the United Nations Framework Convention on Climate Change, which defines "climate change" as: "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods."

As defined in this report, the goal of adaptation is to reduce the risk of adverse environmental outcomes through activities that increase the resilience of ecological systems to climate change. Here, resilience refers to the amount of change or disturbance that a system can absorb without undergoing a fundamental shift to a different set of processes and structures. Managers' past experiences with unpredictable and extreme events have already led to some existing approaches that can be adjusted for use in adapting to longer-term climate change. The specific "adaptation approaches" described below are derived from discussions of existing (and new) management practices to maintain or increase ecosystem resilience, drawn from across the chapters of this report.

Protecting key ecosystem features involves focusing management protections on structural characteristics, organisms, or areas that represent important "underpinnings" or "keystones" of the overall system. **Reducing anthropogenic stresses** is the approach of minimizing localized human stressors (*e.g.*, pollution, fragmentation) that hinder the ability of species or ecosystems to withstand climatic events. **Representation** refers to protecting a portfolio of variant forms of a species or ecosystem so that, regardless of the climatic changes that occur, there will be areas that survive and provide a source for recovery. **Replication** centers on maintaining more than one example of each ecosystem or population such that if one area is affected by a disturbance, replicates in another area provide insurance against extinction and a source for recolonization of affected areas. **Restoration** is the practice of rehabilitating ecosystems that have been lost or compromised. **Refugia** are areas that are less affected by climate change than other areas and can be used as sources of "seed" for recovery or as destinations for climate-sensitive migrants. **Relocation** refers to human-facilitated transplantation of organisms from one location to another in order to bypass a barrier (*e.g.*, urban area).

Each of these adaptation approaches ultimately contributes to resilience, whether at the scale of individual protected area units, or at the scale of regional/national systems. The approaches above are not mutually exclusive and may be implemented jointly. The specific management activities that are selected under one or more approaches above should then be based on considerations such as: the ecosystem management goals, type and degree of climate effects, type and magnitude of ecosystem responses, spatial and temporal scales of ecological and management responses, and social and economic factors.

Levels of confidence in these adaptation approaches vary and are difficult to assess, yet are essential to consider in adaptation planning.

Due to uncertainties associated with climate change projections as well as uncertainties in species and ecosystem responses, there is also uncertainty as to how effective the different adaptation approaches listed above will be at supporting resilience. It is therefore important to assess the confidence within the expert community that these approaches will support a degree of resilience that may allow ecosystems to persist without major losses of ecosystem processes or functions. Using one of the methodologies presented in the Intergovernmental Panel on Climate Change's guidelines[2] for estimating uncertainties, the authors of this report developed their

[2] Guidance on uncertainty from *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E.

confidence estimates by considering two separate but related elements of confidence. The first element is the amount of available evidence (high or low) to support the determination that the effectiveness of a given adaptation approach is well-studied and understood. Evidence might consist of any of the following sources: peer-reviewed and gray literature, data and observations, model results, and the authors' own experience with each adaptation approach. The second element is the level of agreement or consensus throughout the scientific community about the different lines of evidence on the effectiveness of the adaptation approach.

The resulting confidence estimates vary, both across approaches and across management systems. Reducing anthropogenic stresses is one approach for which there is considerable scientific confidence in its ability to promote resilience for virtually any situation. Confidence in the other approaches—including protecting key ecosystem features, representation, replication, restoration, identifying refuges, and especially relocation—is much more variable. Despite this variability, many of the individual adaptation options under these approaches may still be effective. In these cases, a more detailed assessment of confidence for individual adaptation options is needed, based on a clearer understanding of how the ecosystem in question functions, the extent and type of climate change that will occur there, the resulting ecosystem impacts, and the projected ecosystem response to the adaptation option.

One method for integrating confidence estimates into resource management given uncertainty is adaptive management. Adaptive management is a process that promotes flexible decision-making so that adjustments are made in decisions as outcomes from management actions and other events are better understood. This method supports managers in taking action today using the best available information while also providing the possibility of ongoing future refinements through an iterative learning process.

The success of adaptation strategies may depend on recognition of potential barriers to implementation and creation of opportunities for partnerships and leveraging. In many cases, perceived barriers associated with legal or social constraints, restrictive management procedures, limitations on human and financial capital, and gaps in information may be converted into opportunities. For example, there may be a possibility to address difficulties associated with information or capacity shortages through leveraging of human capital. Existing staff could receive training on addressing climate change issues within the context of their current job descriptions and management frameworks, but a critical requirement for success of this activity would be to ensure that employees feel both valued as "climate adaptation specialists" and empowered by their institutions to develop and implement innovative adaptive management approaches that might be perceived as "risky." As a second example, partnerships among managers, scientists, and educators can go a long way toward efficiently closing information gaps. With good communication and coordination, scientists can target their research to better inform management challenges, resource managers can share data and better design monitoring to test scientific hypotheses, and outreach specialists can better engage the public in understanding and supporting adaptation activities. Two additional categories of opportunities that are especially promising are highlighted below.

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The Nation's adaptive capacity can be increased through expanded collaborations among ecosystem managers.

When managers seize opportunities to link with other managers to coordinate adaptation planning, they are able to broaden the spatial and ecological scope of potential adaptation options with a shared vision for increasing adaptive capacity. For example, many management units are nested within or adjacent to other systems. Collaboration across systems allows individual units to be, in effect, extended beyond their official boundaries to encompass entire ecosystems or regions; the result is a larger array of options for responding to future climate change impacts. Collaboration may also enhance research capacity and offer opportunities to share data, models, and experiences. In addition to overcoming limiting factors such as inadequate resources and mismatches of management unit size with ecosystem extent, collaborations may also be used to create flexible boundaries that follow unanticipated changes in ecosystems or species in response to climate change. Exercising opportunities for collaboration has the advantage of reducing uncertainties associated with attaining management goals under climate change because (1) the increase in the geographic range over which resources can be managed and the associated increase in available adaptation options makes success more likely, and (2) the increase in the resource base, in research capabilities, and in the size of data sets through data sharing and coordinated monitoring reduces statistical uncertainties and increases the probability of success.

The Nation's adaptive capacity can be increased through creative re-examination of program goals and authorities.

Anticipated climate-induced changes in ecosystems and species and the uncertain nature of some of those changes will necessitate dynamic management systems that can accommodate and address such changes. Existing management authorities may be malleable enough to allow for changing conditions and dynamic responses, and with creative re-examination of those authorities their full capabilities could be applied. For example, federal land and water managers may be able to strategically apply traditional legislative authorities in non-traditional ways to coordinate management outside of jurisdictional boundaries. Similarly, while management policies can sometimes be limiting, the iterative nature of management planning may allow priorities and plans to be revisited on a cyclical basis to allow for periodic adjustments. Greater agility in program planning can increase the probability of meeting management goals by overcoming implementation barriers associated with narrowly defined and interpreted authorities.

Establishing current baselines, identifying thresholds, and monitoring for changes will be essential elements of any adaptation approach.

Climate changes may cause ecological thresholds to be exceeded, leading to abrupt shifts in the structure of ecosystems. Threshold changes in ecosystems have profound implications for management because such changes may be unexpected, large, and difficult to reverse. If these ecosystems cannot then be restored, actions to increase their resilience will no longer be viable. Understanding where thresholds have been exceeded in the past and where (and how likely) they may be exceeded in the future allows managers to plan accordingly and avoid tipping points where possible. Activities taken to prevent threshold changes include establishing current baseline conditions, modeling a range of possible climate changes and system responses, monitoring to identify relevant

ecological changes, and responding by implementing adaptation actions at appropriate scales and times. Current baselines capture a benchmark set of conditions for the ecological attributes or processes that are critical for maintaining that system and the current set of ecosystem services that the public has come to expect from that system. Developing a range of quantitative or qualitative visions of the future (scenarios) and planning adaptation responses for that range provide an approach for addressing the large uncertainties associated with any single projection of the future. Sensitivity analyses for any given scenario explore key attributes of the system and their response to systematic changes in the climate drivers. Such analyses may allow managers to identify thresholds beyond which key management goals may become unattainable. Directed monitoring then supports managers' ability to detect changes in baseline conditions, informs their decisions about the timing of adaptation actions, and helps them evaluate the effectiveness of their actions. With such information, a program that has the authority to, for example, acquire land interests and water rights to restore a river to its historic flows would better be able to determine how, when, and where to use this authority.

Beyond "managing for resilience," the Nation's capability to adapt will ultimately depend on our ability to be flexible in setting priorities and "managing for change." Prioritizing actions and balancing competing management objectives at all scales of decision making is essential, especially in the midst of shifting budgets and rapidly changing ecosystems. Using a systematic framework for priority setting would help managers catalog information, design strategies, allocate resources, evaluate progress, and inform the public. This priority-setting could happen in an ongoing way to address changing ecological conditions and make use of new information. Over time, our ability to "manage for resilience" of current systems in the face of climate change will be limited as temperature thresholds are exceeded, climate impacts become severe and irreversible, and socioeconomic costs of maintaining existing ecosystem structures, functions, and services become excessive. At this point, it will be necessary to "manage for change," with a re-examination of priorities and a shift to adaptation options that incorporate information on projected ecosystem changes. Both "managing for resilience" and "managing for change" require more observation and experimentation to fill knowledge gaps on how to adapt to climate change. This report presents a preliminary review of existing adaptation knowledge to support managers in taking immediate actions to meet their management goals in the context of climate change. However, this is only a first step in better understanding this burgeoning area of research in adaptation science and management. It will be necessary to continuously refine and add to this body of knowledge in order to meet the challenge of preserving the Nation's lands and waters in a rapidly changing world.