I. Introduction

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Our Rapidly Changing World

Rapid changes in the earth's **climate*** are well underway, and more and larger shifts are expected, even under the best-case scenarios for **greenhouse gas** emissions reductions. It is clear from current trends and future projections that the planet's living resources—humans, plants, and animals alike—will exist in an environment in the future that will be vastly different from the one we have experienced over the past century, during which our conservation traditions evolved.

Since the release of the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) in 2007 (IPCC 2007a, 2007b, 2007c, 2007d), new evidence that our planet is experiencing significant and irreversible changes has underscored reasons for concern (Smith, et al. 2009). In the United States, we are seeing a multitude of changes consistent with a rapidly warming climate. Climate change impacts in the United States summarized by the U.S. Global Change Research Program in *Global Change Impacts in the United States* (USGCRP 2009, p. 27) include:

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*Terms highlighted in blue are defined in the Glossary.

- U.S. average temperature has risen more than 2 degrees Fahrenheit over the past 50 years and is projected to rise more in the future; how much more depends primarily on the amount of heat-trapping gases emitted globally and how sensitive the climate is to those emissions.

- Precipitation has increased an average of about 5 percent over the past 50 years. Projections of future precipitation generally indicate that northern areas will become wetter, and southern areas, particularly in the West, will become drier.

- The amount of rain falling in the heaviest downpours has increased approximately 20 percent on average in the past century, and this trend is very likely to continue, with the largest increases in the wettest places.

- Many types of extreme weather events, such as heat waves and regional droughts, have become more frequent and intense during the past 40 to 50 years.

- The destructive energy of Atlantic hurricanes has increased in recent decades. The intensity of these storms is likely to increase in this century.

- In the eastern Pacific, the strongest hurricanes have become stronger since the 1980s, even while the total number of storms has decreased.

- Sea level has risen along most of the U.S. coast over the last 50 years, and will rise more in the future.

- Cold-season storm tracks are shifting northward and the strongest storms are likely to become stronger and more frequent.

- Arctic sea ice is declining rapidly and this is very likely to continue.

These changes are already having a considerable impact on species and natural systems, including changes in the timing of biological events (i.e., phenological changes), such as the onset and end of breeding seasons, migration, and flowering; shifts in geographic ranges; and changes in community dynamics and populations (U.S. CCSP 2008a). For example:

- Across North America, plants are leafing-out and blooming earlier; birds, butterflies, amphibians, and other wildlife are breeding or migrating earlier; and species are shifting or expanding their ranges, often northward and to higher elevations (Parmesan and Galbraith 2004; Kelly and Goulden 2008; Root et al. 2005).

- Increased water temperatures in coral reefs in southern Florida, the Caribbean, and Pacific Islands have contributed to unprecedented bleaching and disease outbreaks (Donner et al. 2006; Harvell et al. 2007).

- Severe storm events, sea-level rise, and saltwater intrusion have led to a decline in coastal wetland habitats from the Atlantic Coast to the Gulf of Mexico (Janetos et al. 2008; Kennedy et al. 2002).

- Salmonids throughout the Pacific Northwest are now challenged by global warming–induced alteration of habitat conditions throughout their complex life cycles (ISAB 2007).

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- Forest and grassland systems throughout the West have been stressed by drought, catastrophic wildfires, insect outbreaks, and expansion of invasive species (Ryan et al. 2008).

These and other changes are bellwethers for what scientists project will be even more dramatic impacts for many species, habitats, and ecosystems in the decades to come. Even with the acknowledgement that there is considerable uncertainty in climate change projections, the underlying message is clear: widespread changes already are occurring, they will continue, they will expand in scope and scale in the next few decades due to greenhouse gases already in the atmosphere, and they will expand even more over longer time horizons if greenhouse gas emissions continue unabated or increase.

Adaptation is rapidly becoming the primary lens for conservation and natural resource planning and management.

Climate Change Adaptation—Putting Vulnerability Assessment in Context

The potential for far-reaching impacts of **climate change** are driving a fundamental shift in conservation and natural resource management. Managers can no longer look exclusively to the past to guide their conservation and restoration goals, but instead must anticipate an increasingly different and uncertain future (Milly et al. 2008). We will need to make conservation decisions based on longer time frames (e.g., over several decades) than we have traditionally considered. Addressing climate change will also require us to design and implement research and conservation efforts at larger landscape and biogeographical scales, often spanning multiple institutional and political jurisdictions (Opdam and Wascher 2004). Further complicating matters, climate change does not occur in a vacuum. Indeed, it is the combined effects of climate change and existing problems such as habitat fragmentation that ultimately pose the greatest threat to our natural systems and the fish, wildlife, and people they support (Root and Schneider 2002).

Climate change adaptation is the emerging discipline that focuses on helping people and natural systems prepare for and cope with the impacts of climate change (Glick et al. 2009). Indeed, adaptation is rapidly becoming the primary lens for conservation and natural resource planning and management.

Until recently the human response to climate change has focused largely on efforts to reduce the greenhouse gas emissions that are the underlying driver of climate change and global warming. Adaptation efforts serve as an essential complement to such climate change “mitigation” efforts. Adaptation, however, has only recently begun to be widely acknowledged and embraced as a response to the challenges of climate change. As a result, the adaptation science and practice is still in an early developmental stage and is evolving rapidly (Heller and Zavaleta

2009). Additionally, much of the early thinking and work on adaptation has been targeted, understandably, toward protecting human communities and infrastructure from climate impacts, with limited attention to date on safeguarding the natural systems that sustain both people and wildlife.

Developing meaningful adaptation strategies requires an understanding of, first, the impacts, risks, and uncertainties associated with climate change, and second, the vulnerability of the different components of our natural world to those changes. In this context, **vulnerability** to climate change refers to the extent to which a species, habitat, or ecosystem is susceptible to harm from climate change impacts (Schneider et al. 2007). More vulnerable species and systems are likely to experience greater impacts from climate change, while less vulnerable species and systems will be less affected, or may even benefit. Accordingly, climate change adaptation can be defined as "initiatives and measures designed to reduce the vulnerability of natural systems to actual or expected climate change effects" (IPCC 2007d).

Adaptation refers to measures designed to reduce the vulnerability of systems to the effects of climate change.

Key Adaptation Concepts

A considerable body of knowledge is now emerging focusing on ecosystem or natural resource-based adaptation (Groves et al. 2010; West et al. 2009; Lawler 2009; Mawdsley et al. 2009; Glick et al. 2009). Adaptation efforts generally fall under one or more of the following approaches: (1) building *resistance* to climate-related stressors as a way of maintaining high-priority species or systems; (2) enhancing *resilience* in order to provide species and systems with a better chance for accommodating and weathering changes; and (3) anticipating and facilitating ecological *transitions* that reflect the changing environmental conditions. In the climate change adaptation literature, **resistance** typically refers to the ability of a system (e.g., and ecosystem, species, population, etc.) to withstand a disturbance or change without significant loss of ecological structure or function (U.S. CCSP 2008b; Heller and Zavaleta 2009; Nyström et al. 2008; Williams et al. 2008; Walker et al. 2004; Easterling et al. 2004; Hansen and Biringer 2003). In other words, the species or ecosystem can tolerate or avoid the impacts of altered air or water temperatures, extreme events, and/or other climate change variables altogether. **Resilience**, in an adaptation context, generally refers to the ability of a system to recover from a disturbance or change without significant loss of function or structure, and to return to a given ecological state, rather than shift to a different state (Gunderson 2000).

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Coral reefs provide a useful illustration of these concepts. One of the primary ways in which climate change is affecting coral reefs is through higher average sea surface temperatures, which is contributing to an increase in the frequency and extent of

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coral bleaching events around the world (Hoegh-Guldberg et al. 2007). A coral reef may be able to avoid bleaching and its associated mortality if, for example, local upwelling draws cooler water to the surface where that reef is located (Grimsditch and Salm 2006). Similarly, a coral reef may be resilient to a coral bleaching event if, after experiencing bleaching during a period of high ocean temperatures, the coral ecosystem recovers and continues to function as a coral-dominated system. On the other hand, conditions may be such that the reef system may not be able to withstand or recover from a major bleaching event (e.g., adverse temperature conditions may be prolonged and/or multiple climate and non-climate stressors may be at play). Recently, the conversion of coral-dominated reefs to algal-dominated reefs in some areas following mass bleaching and mortality is a strong indication of decreased resilience of these systems (Hughes et al. 2003).

Managing for ecological transitions will be an increasingly significant part of our conservation agenda.

While efforts to promote or maintain ecosystem resilience are among the most commonly recommended strategies for climate change adaptation, it will also be important to develop strategies that actually enable or facilitate the ability of a species or ecosystem to change in response to global warming, not just avoid or bounce back from the impacts (Heller and Zavaleta 2009; Galatowitsch et al. 2009).). In all likelihood, measures to manage for ecological transitions are going to be an increasingly significant part of our conservation agenda.

Although relevant adaptation strategies will vary considerably based on specific circumstances, several general adaptation principles are broadly applicable:

- **Reduce existing stressors.** Climate change will exacerbate many existing threats to our wildlife and natural ecosystems, such as the loss of habitat and spread of invasive species. Reducing those existing stressors that interact negatively with climate change will often be key to promoting ecosystem resilience.

- **Manage for ecosystem function.** Healthy and biologically diverse ecosystems will be better able to withstand or bounce back from the impacts of climate change.

- **Protect refugia and improve habitat connectivity.** Identifying and protecting both existing and possible future strongholds of wildlife populations and wildlife corridors will be important for helping sustain the full array of species, ecosystems, and their human benefits. Ensuring connectivity among these core habitat areas will facilitate the ability of species to shift ranges in response to changing climates.

- **Implement proactive management and restoration.** Efforts that actively *facilitate* the ability of species, habitats, and ecosystems to accommodate climate change—for example, beach nourishment, enhancing marsh accretion, and planting climate change-resistant species—may be necessary to protect highly valued species or ecosystems when other options are insufficient.

Vulnerability Assessment: A Tool for Adaptation Planning

The conservation and resource management community is now being challenged to take the type of general principles described above and develop climate change adaptation plans that address specific on-the-ground needs. Ensuring that these plans are truly "climate-smart" and do not simply represent relabeled business-as-usual will require that managers go through an explicit process for bringing climate data and ecological understanding to bear on their planning.

Climate change vulnerability assessment represents a key tool for providing adaptation planning efforts with such explicit climate input. Vulnerability assessments can provide two essential types of information needed for adaptation planning:

1. Identifying ***which*** species or systems are likely to be most strongly affected by projected changes

2. Understanding ***why*** they are likely to be vulnerable

Determining *which* resources are most vulnerable enables managers to better set priorities for conservation action, while understanding *why* they are vulnerable provides a basis for developing appropriate management and conservation responses.

Figure 1.1 offers an overall framework for adaptation planning, indicating how vulnerability assessments can fit into and support that process. Elements of this framework should look familiar to many conservationists because it draws from a number of existing conservation planning frameworks, such as The Nature Conservancy's *Conservation by Design* (TNC 2006) and the U.S. Fish and Wildlife Service's Strategic Habitat Conservation framework (U.S. FWS 2009a).

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Kyle Barrett

Element 1: The framework starts with identifying conservation targets, whether they be species, habitats, ecosystems, or some other unit. **Element 2:** These conservation targets are then assessed for their vulnerability to climate change in order to determine which are likely to be most at risk and which are more likely to persist. **Element 3:** Based on an understanding of why the species or systems are regarded as vulnerable to climate change and other stressors, an array of management options can be identified and evaluated based on technical, financial, and legal considerations. **Element 4:** Selected management strategies can then be implemented, with the activities and outcomes subject to monitoring in order to feed into a regular cycle of evaluation, correction, and revision. Climate change is not occurring in a vacuum, and the elements of the adaptation planning process must also take existing stressors into consideration as well as other relevant factors affecting the system.

This guide focuses on how vulnerability assessment (Element 2) can support conservationists and natural resource managers as we move into a future that does not necessarily have past analogs. For although these assessments must be strongly science based, they are not simply scientific assessments; rather, they must be viewed as an integral part of a broader adaptation planning and implementation framework.

Overarching Conservation Goal(s)

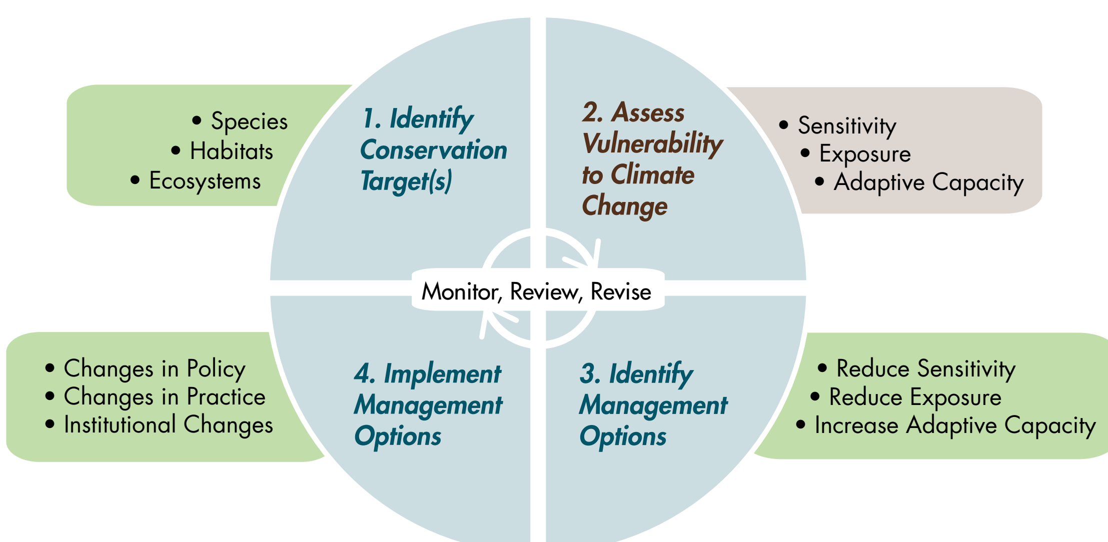

Figure 1.1. Framework for Developing Climate Change Adaptation Strategies

Box 1.1 "Top-Down" vs. "Bottom-Up" Approaches to Adaptation Planning

The process of developing a climate change adaptation strategy can be approached from either a "top-down" or "bottom-up" perspective, or some combination of these. The most appropriate approach will depend on the scale and goals of your strategy, which in turn will help guide the design of your vulnerability assessment (Hansen and Hoffman 2011). A top-down approach generally starts with looking at one or more scenarios for shifts in climate (e.g., projections for sea-level rise, temperature changes, or extreme rainfall events); assessing what the future landscape might look like under those scenarios (e.g., what are the plausible ecological effects of the projected physical changes); and finally setting specific conservation objectives and management priorities designed to address those projected future changes. This approach is particularly useful for broad-scale efforts, such as those conducted at regional or national levels, focused on regional ecosystem or biomes, or that have multiple species as conservation targets. A bottom-up approach, on the other hand, usually starts with an organization or agency's specific conservation or management goals (e.g., protecting critical habitat for a particular endangered species, managing a specific wildlife refuge, or setting maximum allowable pollutant levels); identifying how climatic variables influence those conservation goals (e.g., the influence of temperature on species' health and reproduction or on the toxicity of pollutants); determining plausible physical and ecological changes under a range of climate scenarios; and finally identifying and evaluating options for reducing the vulnerability of the agency's goals to those projected changes.

Why Assess Vulnerability?

As described above, vulnerability assessments are key tools for the development of climate change adaptation strategies. We would like to highlight in particular three key motivations for carrying out vulnerability assessments:

- Help in setting management and planning priorities
- Assist in informing and crafting adaptation strategies
- Enable more efficient allocation of scarce resources

Mark Karrass

Set Management and Planning Priorities

Vulnerability assessments help resource managers better understand the relative susceptibility of the species, habitats, ecosystems, or special places they are working to protect to the likely future impacts of climate change. They help answer two related questions regarding setting priorities. First, they help us identify answers to the question: "What should we be doing differently in light of climate change?" Just as important, however, they also help clarify answers to the question: "Which of our existing activities and management actions continue to make sense in a climate change context?" Focusing our conservation efforts with an explicit climate perspective will give us a greater chance of success in evaluating current conservation and management objectives to determine if they should be adjusted and if so, how, and in designing effective approaches for reaching our objectives. In cases where the potential impacts of climate change are highly uncertain, managers may initially focus on so-called "no regrets" strategies, which provide conservation benefits whether or not the projected magnitude of climate changes actually occur.

The following are simplified examples of how climate change vulnerability assessments might help inform conservation plans:

1. A coastal organization concerned about preserving an important sea turtle nesting site commissions a study that shows that the region is at substantial risk of being inundated due to rising sea levels. Although there is uncertainty about how much sea-level rise will occur and when at their site, loss of most or all of the nesting site is considered highly likely. The organization can then plan to acquire or secure a long-term easement for land inland of the current site to provide an additional habitat "buffer" (i.e., protect a greater amount of existing habitat area than is considered sufficient under current conditions) or perhaps accommodate potential habitat migration (i.e., the transformation of "new" areas inland into habitat with suitable conditions for nesting). Without an understanding of the potential impacts of sea-level rise, the organization's resources might have been spent in other directions, and the option of conserving habitat for a new nesting site may have been ultimately lost to development or other uses.

2. Land managers are concerned about an invasive plant or insect species that has been spreading across areas to the south of their current location. Model simulations project that these species will expand into their region due to higher temperatures and increased disturbances from wildfires. They decide to proactively devote additional resources toward halting the spread of this invasive before it arrives in the region. Such efforts may not have been viewed as a priority if those new areas were not identified as a viable habitat in which the particular invasive species might thrive. In other areas, land managers may decide to lessen or abandon efforts to fight invasive species where studies suggest climate change may do the job for them—for example, as models project drier conditions that will no longer support the invader.

Inform and Craft Adaptation Strategies

Vulnerability assessments can also inform the development of effective management strategies for meeting a conservation goal that considers climate change as an added stressor. As will be elaborated on later, vulnerability consists of three components—sensitivity, exposure, and adaptive capacity—and adaptation strategies can be designed either to reduce the sensitivity and/or exposure of a species or system, or to increase its adaptive capacity. For example:

1. Climate change may be contributing to an increase in average water temperatures in an important trout stream. Targeted measures to help moderate those temperatures, such as expanding riparian

Box 1.2. Adaptation and Adaptive Management: Complementary but Distinct Concepts

Adaptation and adaptive management are distinct concepts that are frequently confused with one another. As described earlier, adaptation refers to strategies designed to prepare for and cope with the effects of climate change. Because of the uncertainties associated with predicting the effects of future climates on species and ecosystems, flexible management will almost certainly be a component of well-designed adaptation strategies.

In contrast, adaptive management is one particular approach to management in the face of uncertainty, and is not necessarily tied to climate change. Adaptive management has been described as an iterative learning process producing improved understanding and management over time (Williams et al. 2007). Most portrayals of adaptive management describe a cyclical process in which: management goals are defined based on current understanding and predictive models but with key uncertainties explicitly highlighted; management actions are carried out and monitored, and outcomes are compared to predictions; and refinements are made to goals and actions based on real-time learning and knowledge generation.

While it is a common complaint that current environmental rules and regulations lack the flexibility needed for true adaptive management, the Department of the Interior's technical guide to adaptive management (Williams et al. 2007) provides both suggestions for and examples of effective adaptive management in the federal context.

Adaptation to climate change is characterized by making decisions in the face of uncertainty. While the adaptive management framework is structured to enable managers to act in the face of uncertainty, other management approaches and philosophies, as discussed in Chapters V and VI, are also designed to address different levels of uncertainty.

To summarize, adaptive management can be an important component of adaptation efforts, but not all adaptive management is climate change adaptation, nor is all climate change adaptation necessarily adaptive management.

vegetation, protecting cold-water refugia, or increasing cold-water spill from existing reservoirs, could become an important part of trout conservation in the area. Such actions would help reduce that species' exposure to adverse conditions.

2. Coastal marshes may be in danger of being flooded by rising sea levels. A conservation action that may not have been considered without knowledge of likely impacts of climate change is the use of proactive measures to assist in the accretion of sediments as a means for the marsh to keep up with rising waters. Chapter VI provides more detail about how to use the results of vulnerability assessments in the context of developing climate change adaptation strategies.

Allocate Scarce Resources

It follows from the aforementioned reasons that the results of vulnerability

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assessments can help wildlife managers allocate scarce conservation resources more efficiently (Marsh et al. 2007). For example:

1. Vulnerability assessments may steer managers away from potentially costly conservation measures that may have a low likelihood of being efficacious due to climate change, such as restoration of a particular habitat type in an area where assessments indicate continued habitat suitability is highly unlikely.

The choice of whether to focus conservation efforts on the most vulnerable or most viable will be based not only on science, but also on social, economic, and legal values.

2. Managers may decide to spend more of their budget on increased and well-designed monitoring efforts, which will be particularly important to help fill knowledge gaps and reduce uncertainty about climate change impacts over time. Long-term, appropriately designed monitoring is a critical component of **adaptive management,** which is likely to play an important role in the development and implementation of climate change adaptation strategies (see Box 1.2).

What Vulnerability Assessments Won't Do

It is equally important to understand what climate change vulnerability assessments will not do. Although these assessments can provide information about the levels and sources of vulnerability of species or systems to help in setting priorities, the assessments alone do not dictate what those priorities should be. Managers increasingly will be faced with the dilemma of deciding how to invest scarce resources to address various conservation needs. Vulnerability assessments can provide a factual underpinning for differentiating between species and systems likely to decline and those likely to thrive. The choice of whether to focus conservation efforts on the most vulnerable, the most viable, or a combination of the two, will of necessity be based not only on scientific factors, but also social, economic, and legal values. Although uncomfortable to consider, policy-makers, managers, and society as a whole increasingly will be called upon to make

Box 1.3. The Evolution of Climate Change Vulnerability Assessments

Vulnerability assessments have been used for decades in a wide range of sectors to address a wide range of risks. They may target a single risk (e.g., terrorism) or multiple risks (e.g., assessing all sources of vulnerability for an endangered species). The development of climate change vulnerability assessments is part of this ongoing history, adding a new suite of risks for regulators, managers, businesses, and others to consider. Vulnerability to climate change may be investigated in a stand-alone assessment, but in many cases it will be more effective to include it as part of broader vulnerability assessments addressing a range of risks.

As the scientific understanding of the potential and observed impacts of climate change has grown over the past two decades, so too has the interest in developing useful definitions and frameworks for conducting climate change vulnerability assessments (Füssel and Klein 2005). Earlier efforts tended to focus on developing frameworks for assessing the vulnerability of agriculture, public health, and other human systems to climate change, building on approaches used in addressing problems such as poverty, famine, and natural hazards (e.g., Bohle et al. 1994; Handmer et al. 1999; Kelly and Adger 2000; Downing and Patwardhan 2003). More recently, attention also has been placed on assessing the vulnerability of natural systems (species, habitats, and ecosystems) to climate change (Nitschke and Innes 2008; Zhao et al. 2007), as well as multi-disciplinary efforts to assess the vulnerability of ecosystem services to humans (Metzger et al. 2005) and the interactions between multiple stressors (Turner et al. 2003).

Within each of these areas, however, different definitions and concepts for climate change vulnerability have emerged, which often has led to misunderstandings and challenges in assessment efforts (Füssel 2007). In this guide, we followed the general framework adopted by the IPCC (2001a, 2007c), and subsequently by many others, in which vulnerability assessments are founded on evaluations of exposure, sensitivity, and adaptability to climate changes. The information in this guide provides a general framework for assessing vulnerability of natural systems to climate change, drawing from and building on some of the major concepts gleaned from the literature and attained in practice.

difficult triage choices. Conservation long has been described as a marriage of art and science and that will continue to hold true. Making decisions in the face of climate change will depend on a combination of sound science and practical experience modulated by societal values.

Climate change vulnerability assessments will not provide an estimate of extinction risk or provide the sole basis for determining whether a species ought to receive protection under the Endangered Species Act (ESA). The types of information used in climate change vulnerability assessments can, however, provide information useful in considering the status of a species in relation to the ESA's requirements. For example, information about vulnerability of species and their habitats to climate change, including uncertainty, has been one of the key

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elements considered in several U.S. Fish and Wildlife Service decisions recently under the ESA. These have included: listing the polar bear under the ESA as a threatened species (U.S. FWS 2008a); identifying the Rio Grande cutthroat trout as a candidate of listing (U.S. FWS 2008b); revising critical habitat designated for the Quino checkerspot butterfly (U.S. FWS 2009b); and determining that the American pika, both at the species and subspecies levels, does not warrant listing under the ESA (U.S. FWS 2010).

Finally, there is a permeable boundary between where climate change vulnerability assessments stop and where later components of adaptation planning begin. In this document we focus on the role of vulnerability assessments in providing insights into the relative vulnerabilities of species, habitats, and ecosystems, and understanding the factors involved in those vulnerabilities and other stressors, some of which may be exacerbated by climate change. Adaptation planning also requires the identification, evaluation, and selection of potential management responses to address those vulnerabilities. In practice, some vulnerability assessment efforts go to this next level to identify management responses (e.g., Case Study 6), while others do not. This guidance document does not attempt to address detailed techniques and approaches for identifying, evaluating, and selecting such adaptation responses. However, one increasingly common technique for taking the process to the next step is the use of scenario-based management planning, a technique for decision-making in the face of high uncertainty, which is discussed in Chapter VI.