II. Vulnerability Assessment Basics

This chapter highlights the overarching principles of climate change vulnerability assessments in the context of fish and wildlife management and discusses general considerations in the design of an assessment, including the critical first step of determining scope and objectives. The next chapter (Chapter III) provides more detailed guidance on how to conduct a vulnerability assessment once those goals and objectives have been established. Although the specifics may vary, Box 2.1 summarizes the key steps to carrying out a climate change vulnerability assessment as: (1) determining objectives and scope, (2) gathering relevant data and expertise, (3) assessing the various components of vulnerability, and (4) applying the assessment in adaptation planning and resource management.

Components of Vulnerability

The IPCC defines vulnerability as a function of the *sensitivity* of a particular system to climate changes, its *exposure* to those changes, and its *capacity to adapt* to those changes (IPCC 2007c). **Sensitivity** is a measure of whether and how a species or system is likely to be affected by a given change in climate. **Exposure** is a measure of how much of a change in climate and

Box 2.1. Key Steps for Assessing Vulnerability to Climate Change

Determine objectives and scope

- Identify audience, user requirements, and needed products
- Engage key internal and external stakeholders
- Establish and agree on goals and objectives
- Identify suitable assessment targets
- Determine appropriate spatial and temporal scales
- Select assessment approach based on targets, user needs, and available resources

Gather relevant data and expertise

- Review existing literature on assessment targets and climate impacts
- Reach out to subject experts on target species or systems
- Obtain or develop climatic projections, focusing on ecologically relevant variables and suitable spatial and temporal scales
- Obtain or develop ecological response projections

Assess components of vulnerability

- Evaluate climate sensitivity of assessment targets
- Determine likely exposure of targets to climatic/ecological change
- Consider adaptive capacity of targets that can moderate potential impact
- Estimate overall vulnerability of targets
- Document level of confidence or uncertainty in assessments

Apply assessment in adaptation planning

- Explore why specific targets are vulnerable to inform possible adaptation responses
- Consider how targets might fare under various management and climatic scenarios
- Share assessment results with stakeholders and decision-makers
- Use results to advance development of adaptation strategies and plans

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associated problems a species or system is likely to experience. **Adaptive capacity** refers to the opportunities that may exist to ameliorate the sensitivity or exposure of that species or system. The relationship among these three components is outlined schematically in Figure 2.1. Considering the degree of change (i.e., exposure) that a species or system is projected to experience along with its likely response (i.e., sensitivity) to those changes determines the potential impact. Understanding the likely consequences (i.e., vulnerability), however, requires further consideration of the ability for the species or system to reduce or moderate those potential impacts (i.e., its adaptive capacity).

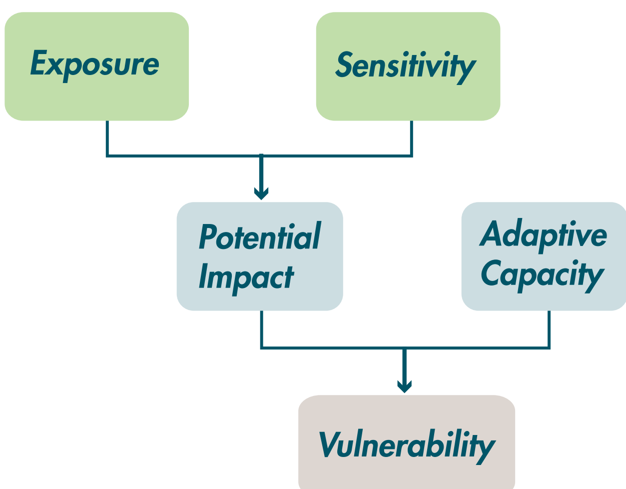


Figure 2.1. Key components of vulnerability, illustrating the relationship among exposure, sensitivity, and adaptive capacity.

Sensitivity

The sensitivity of a species, habitat, or ecosystem to climate change reflects the degree to which that system is or is likely to be affected by or responsive to those changes. Sensitivity may depend on innate physiological or biological variables. For example, a species that is already living at the upper end of its biological temperature range may not be able to tolerate increases in the average temperature in its habitat due to climate change. That species is therefore considered to be "sensitive" to at least one element of climate change, higher average temperatures. Conversely, a population already living in hot conditions may have adapted evolutionarily to high temperatures, and may be less vulnerable to warming than other populations of that species adapted to cooler conditions.

Sensitivity also may be a factor of specific physical or ecological factors. For example, a local river habitat that depends on snowmelt to maintain sufficient instream flows for fish and wildlife is likely to be sensitive to projected reductions in average snowpack due to climate change, as well as to changes in the timing and intensity of precipitation. Finally, sensitivity to climate change impacts may be highly influenced by the existence and extent of other human-related stressors, such as habitat fragmentation due to roads and other development, which can limit the ability of a species to shift ranges in response to changing climate conditions and associated shifts in habitats or ecosystem processes important for the life cycle of the species. In addition, a problem such as unsustainable harvest may increase the sensitivity of a species to climate change by reducing the genetic diversity of individuals within that population. Some of these factors may be considered part of the *adaptive capacity* of a species or system, rather than an element of sensitivity (see below). Additional details on aspects of sensitivity and methods for assessing it are provided in Chapter III.

Exposure

Even if a particular species or system is inherently sensitive to climate change, its vulnerability also depends on the character, magnitude, and rate of changes to which it is exposed. This includes exposure to not only the physical climate changes (e.g., temperature and precipitation) but also to related factors such as altered fire regimes, shifts in vegetation types, increased salinity due to sea-level rise, location of the species or system on the landscape (e.g., latitude and elevation), etc. For example, a specific population of a temperature-sensitive species may inhabit an area likely to be sheltered from rapid temperature increases, such as a north-facing, highly vegetated forest or a high-elevation headwater stream (i.e., refugia). In such instances, the population may have a lower vulnerability than others of its species given its lower level of exposure.

Box 2.2. A Burning Example of Vulnerability

Sunburn is an easily grasped (albeit sometimes painful) example of how the components of vulnerability relate to one another.

- **Sensitivity.** Fair-skinned individuals are usually more sensitive to sunburn than those with deeper skin tones. This sensitivity has a clear biological basis: the skin pigment melanin absorbs ultraviolet (UV) radiation, which is the primary cause of sunburn. As a result, the skin of individuals with lower melanin levels is innately more prone to burning than that of individuals with higher concentrations of melanin.

- **Exposure.**. Depending on one's exposure to UV rays, even individuals with high levels of melanin can burn. In this instance, exposure is related to both the strength of the sun's rays, which varies by latitude, season, and weather conditions, as well as the number of hours in the sun.

- **Adaptive Capacity.** A variety of intrinsic and extrinsic means exist for ameliorating a person's likelihood of burning, and therefore reducing vulnerability. Options for reducing exposure to UV radiation range from protective clothing and sunscreen to remaining indoors and out of direct sunlight. A person's intrinsic sensitivity to UV rays can also be reduced through graduated exposure to sunlight, leading to a temporarily increased concentration of melanin – a process otherwise known as tanning.

Use of climate change projections at various scales can help managers get a sense for where and how much change might be expected to affect a given conservation target. Depending on availability, vulnerability assessments can take advantage of regional climate change projections (i.e., changes in average temperature or precipitation projected across an entire region) or more geographically explicit (but not necessarily more accurate) data from downscaled climate projections. Both originate from simulations by **climate models,** driven by a range of future scenarios. The climate system can be represented by models of varying complexity, that is, for any one component or combination of components a spectrum or hierarchy of models can be identified. Models differ in such aspects as the number of spatial dimensions, the extent to which physical, chemical, or biological processes are explicitly represented, or the level at which empirical parameterizations are involved.

It is also possible to identify the potential ecological effects associated with climate change through the use of so-called **ecological response models,** which provide ways to assess the sensitivity and potential adaptability or resilience of species, habitats, and ecosystems exposed to climate change impacts (Wormworth and Mallon 2007). There are numerous types of response models, ranging from simple to complex. Some of the most commonly used types of response models are the "habitat and occupancy" models, which can project changes in habitat suitability for one or more species over large geographic areas based on specific habitat criteria (e.g., optimal temperature regimes) and biophysical attributes that a species or community can occupy. Other types include conceptual models, general characterization models, expert opinion models, vegetation/habitat response models, physiologically based models, and ecological models. Chapter IV provides a more detailed discussion of climate and response models and how they may be used in vulnerability assessments.

Adaptive Capacity

The adaptive capacity of a species, habitat, or ecosystem refers to the ability of that particular system to accommodate or cope with climate change impacts with minimal disruption. Broadly, adaptive capacity may be considered a factor of particular internal traits, such as the ability of a species to physically move in search of more favorable habitat conditions, adapt evolutionarily, or modify its behavior as climate changes. Adaptive capacity may also be a factor of external conditions such as the existence of a structural barrier such as urban areas, seawalls, or dikes that may limit the ability of that species or habitat to move, or overharvest that limits the genetic diversity available for evolutionary adaptation.

As mentioned above, some factors could equally well be included as part of adaptive capacity, sensitivity, and exposure, particularly in the case of species-based assessments. However, while there is no hard-and-fast rule about where each of these elements should fit in as part of the overall vulnerability assessment, the distinction may be useful for informing management responses. For example, a species that is highly sensitive to climate change but also has a high adaptive capacity may be considered less vulnerable than a moderately sensitive species with little or no adaptive capacity.

Adaptive capacity is different from specific adaptation measures; it can be considered a "pre-existing condition."

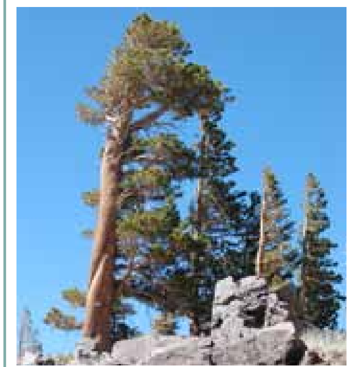
It is important to recognize, as well, that the adaptive capacity of a given conservation target is different from the specific adaptation measures to reduce vulnerability. Essentially, it can be considered as a "pre-existing condition" of that species or system that subsequent adaptation measures can address. For example, some adaptation measures, such as removal of seawalls, may serve to enhance the adaptive capacity of a coastal habitat, thereby reducing its vulnerability to sea-level rise.

Components of Biodiversity

Devising a useful vulnerability assessment not only requires an understanding of the components of vulnerability, but also the components of biodiversity and natural systems so that the most appropriate features can serve as targets of the assessment. Such targets can include species, habitats, or ecosystems, and several sections of this guidance document are structured around those biological levels. The definitions of and terminology for these biological units, however, is often the subject of considerable discussion and debate, and terms like "habitat" can have multiple meanings. For that reason, this section provides a brief summary of the various components of biodiversity and discusses how these concepts and terms are used in the context of vulnerability assessments in this guidance document.

Levels of Biological Diversity

The concept of biological diversity—or biodiversity—has become an overarching framework for characterizing the full variety of life on earth (Wilson 1992; Stein et al. 2000). Although many people think of biodiversity in terms of the array of species that exist in a particular place, the concept is considerably broader and includes at least three biological levels of organization—***genes, species, and ecosystems.*** Most vulnerability assessments focus at either species or ecosystem levels, or include some combination of the two (although genetic factors can come into play in assessing species vulnerabilities). Terminology and application is often widely divergent, however, especially for ecologically defined features (e.g., ecosystem, natural community, vegetation type, habitat type). Usage often differs markedly between academic researchers and land or wildlife managers, and also differs based on regional variations in ecological classification and mapping efforts.



Bruce Stein

Each biological level, in turn, can be viewed as having three primary attributes: ***composition, structure, and function*** (Noss 1990). As an example, a specific forest type can be viewed in terms of its composition (the different species of plants and animals making up and inhabiting the forest), its structure (e.g., overstory trees, midstory shrubs, understory forbs), and its functions (e.g., key ecological processes such as periodic fire or nutrient cycles).

Each biological level can be viewed as having three attributes— composition, structure, and function.

Distinguishing among these three attributes may seem an abstract exercise, but can be important for distinguishing among the climate impacts to a particular species or habitat type. In a particular forest type, for instance, shifting climate may eliminate or decrease the frequency of certain species, translating into an change in composition. Depending upon the affected species, however, that change can also represent a shift in ecosystem structure or function. Pine rocklands in the lower Florida Keys, for example, are characterized by open stands of slash pine with a scrubby understory of palms and shrubs. In 2005 saltwater inundation from hurricane-associated storm surge covered large portions of this habitat on the National Key Deer Refuge on Big Pine Key, causing mortality of the overstory pines (Sah et al. 2010). As a result, this portion of the refuge has been converted from an open woodland to a scrubland, with consequent affects on wildlife values and ecological functioning.

Box 2.3. How Does "Resilience" Fit In?

As discussed in Chapter I, one of the most prominent concepts in the field of climate change adaptation today is resilience. A number of factors can determine whether and to what extent a particular species or ecosystem is resilient to climate change. For example, studies show that diversity at multiple levels (i.e., among different functional groups, species within functional groups, and within species and populations of those species, in addition to species richness itself) is particularly critical for ecosystem resilience (Kareiva et al. 2008; Worm et al. 2006; Folke et al. 2004; Luck et al. 2003; Elmqvist et al. 2003). Essentially, such diversity is like climate "insurance"—if one element of a system is compromised, it is more likely that other elements will still be available to support key ecological processes (Peterson et al. 1998). However, while a more resilient ecosystem might be considered less vulnerable to climate change, where and how to incorporate the concept into a vulnerability assessment is not necessarily clear cut (Gallopin 2007). For example, a system that is considered sensitive to climate change, such as a coral reef, may or may not be resilient (e.g., return to a coral-dominant system after a major bleaching event) (Nyström et al. 2000). It is likely that, in most cases, the concept of resilience in a climate change vulnerability assessment will be considered an element of the adaptive capacity of an ecosystem.

Species and Populations

Individual species of fish, wildlife, and plants often constitute the focus of conservation efforts, and similarly are frequent targets for climate change vulnerability assessments. Such assessments can consider a species at the "full taxon" level, that is, across its entire range, or focus on a geographically defined portion of the species. The geographic subsets may simply be that portion of a species that exists within the area of interest for the assessment, or may reflect biologically defined populations (including subpopulations or metapopulations). Most vulnerability assessments are geographically limited in scope (e.g., a state, region, or place) and will therefore usually consider one or more populations, rather than the species as a whole. Common exceptions include assessments mandated by federal statutes such as the ESA.

In practice, most vulnerability assessments are geographically limited and will consider one or more populations, rather than a species as a whole.

The implication of this is significant in assessing the individual components of vulnerability with respect to a species. Many aspects of *sensitivity* relate to innate characteristics of a species, and would be expected to hold relatively constant across its full range. These might includes factors such as reproductive rate or physiological thresholds. On the other hand, *exposure* is by definition variable depending on location. Given the same level of innate sensitivity a species may be exposed to more change in some portions of its range than others. For example, a temperature-sensitive species may be at risk of exceeding its temperature threshold in the southern portion of its range but not along the northern range boundary. As a result, its overall vulnerability may differ significantly between southern and northern populations. It is also possible that *adaptive capacity* can vary across a species geographic range. In this instance, genetic variation across the species' range may render the plant or animal more or less capable of dealing with climate or ecosystem variability and perturbations.

Habitats and Ecosystems

Terminology related to ecological levels of biodiversity is complex and contentious and tends to provoke interminable discussions and debates about appropriate usage. Among the many terms and concepts involved are: habitat, natural community, biotic community, biological assemblage, ecological community, ecological system, ecosystem, ecoregion, biome, and landscape. It is not the purpose of this guidance document to attempt to define and distinguish among these various terms and concepts, and there are many articles and texts in ecology, wildlife biology, and conservation biology that address aspects of this topic (e.g., Bailey 2009; Jax 2006). Because of the significance of ecologically defined units to the practice of vulnerability assessment, though, it is important to draw a few key distinctions, as well as to clarify the sense in which key terms are used in this guidance document.

In this document, the term "habitat" should be interpreted in its most inclusive and general sense.

Defining "Habitat"

Fish and wildlife managers are accustomed to thinking about habitat in relation to their work, and many if not most conservation activities focus on habitat protection, management, or restoration. In practice, *habitat* generally refers either to the place in which an organism exists, or more specifically, to the biophysical features that provide such things as food, water, and shelter necessary to sustain an organism. In a strict sense, habitats are species specific. That is, habitat is viewed through the prism of a particular organism, constituting those things that are needed by and used by that particular species. Different organisms may have similar or overlapping habitat requirements, but these requirements will virtually always differ either subtly or more conspicuously.

Notwithstanding this organism-centric view of habitat, the term is perhaps even more commonly used to describe and communicate about natural ecosystems and landscapes more generally. In this

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sense, the usage can be extremely broad—referring for instance to natural cover providing some wildlife benefit—or very narrow, applying to a specific and precisely defined vegetation type. Usage of the term in terrestrial systems and for terrestrial organisms most commonly is based on a combination of vegetation cover and physical features (e.g., cliff faces, soil types). In aquatic systems the term commonly is based on physical features such as geomorphology, bottom substrate, and water current velocity.

Habitat classifications are, not surprisingly, highly variable and give rise to an exceptional range of habitat mapping efforts based on different attributes and standards. Habitat classifications and mapping have been standardized in some disciplines and in some states or regions, but not in others. For example, in the northeastern United States, the states have collaborated on the development of a regional habitat classification designed to cross-walk the state-specific habitat types that were the focus of individual state wildlife action plans (Gawler et al. 2008).

Despite variability in usage and meaning, habitat is such a central concept in the practice of conservation—and to key audiences for this guide—that we use the term extensively throughout this guidance document. Unless otherwise noted, in this document the term should be interpreted in its most inclusive and general sense. Habitat-oriented vulnerability assessments can be very powerful tools, but given the varied usage and interpretations of this term, it is essential that when they are used as targets of assessments the basis for the habitats (both in concept and execution) be clearly identified and documented.

Defining "Ecosystem"

Just as the term *habitat* has multiple meanings, so too does the term *ecosystem*. In its classical sense, the term refers to a natural unit consisting of the interaction of living organisms and the physical environment (Odum 1953). This traditional concept of an ecosystem is scaleless in the sense that it can refer to the interaction among biotic and abiotic elements contained within a tiny water-filled depression, or across a million-acre landscape.

As noted above, however, there is a host of terms of varying technical specificity that refer to different types of ecological units. Some focus on the interactions that exist among organisms themselves (e.g., biological communities), some on particular classes of organisms (e.g., vegetation types), while others take a more geographic or landscape-level perspective (e.g., Greater Yellowstone Ecosystem). It is not our intent to descend into the bottomless pit of debating the appropriateness of one set of terms over another. In this document, where the term "ecosystem" is used, it can be taken to refer in a general sense to ecological features or units, and indeed, we often simply refer to "systems."

There are, however, several ecosystem-related concepts that have great applicability for adaptation planning and vulnerability assessment. First, there is a wide gradation in spatial scales for different types of units. As an example, the U.S. National Vegetation Classification provides a fine-scale means of characterizing and mapping vegetation types in a nationally consistent way based primarily on vegetation structure and composition (Grossman et al. 1998). At a somewhat coarser scale, the "Ecological Systems" classification that supports U.S. Geological Survey's Gap Analysis Program (GAP) and the U.S. Forest Service's LANDFIRE effort are based on vegetation structure and composition, as well as underlying ecological processes (Comer et al. 2003). Another promising approach from a climate adaptation standpoint is a focus on conserving the ecological "arena" rather than specific biological "actors" through the use of "land facets"—recurring landscape units with uniform topographic and soil attributes (Beier and Brost 2010; Anderson and Ferree 2010).

Setting Goals and Engaging Stakeholders

Climate change vulnerability assessments are, first and foremost, intended to support decision-making, and as such they should be designed from the start with an eye toward the needs of the end users, whether they be on-the-ground managers, policy-makers, or others in the management or scientific communities. This concept is so important that the National Research Council (2009) lists "begin with users' needs" as its first principle for effective decision support in the face of a changing climate.

Assessments should be designed from the start with an eye toward the needs of the end users.

A critical first step then in conducting a vulnerability assessment is to identify the scope and objectives of the assessment based on the intended audience and uses of the assessment. More than anything else, the audience and decision process the assessment is intended to inform will help shape the contours of the analysis.

In this section we discuss the importance of identifying the audience for and stakeholders in the assessment, determining the appropriate level of stakeholder engagement for your particular assessment, clarifying up-front goals and objectives, and addressing some key considerations that logically relate to meeting those objectives within available time and resources. There are a number of different approaches to assessing climate change vulnerability, which vary in the input requirements and type of outputs. Some approaches are more quantitative and other more qualitative, some are modeling-intensive while others rely more on expert knowledge. There is no one single best approach for conducting a vulnerability assessment. Rather, the right approach for any particular effort will depend on user goals and requirements, including the question being asked and the level of resources—data, expertise, time, and funding—available.

Who Is Your Audience?

Execution of a climate change vulnerability assessment should be geared toward the particular user (which we refer to as the *audience*) who will be using the results. Different audiences will likely warrant different assessment targets, levels of complexity, and approaches to communicate the findings. If the primary goal of conducting a vulnerability assessment is to raise greater public awareness of the threat that climate change poses to fish and wildlife at a regional or national level, it may be sufficient to conduct a review of existing literature on climate change impacts or conduct relatively broad and general assessments and then synthesize that information in understandable and accessible outreach tools. On the other hand, if the intended audience is a refuge or park manager who will be using the data to target specific land acquisitions and restoration investments, then much more fine-scale data and assessment results will be necessary. For example, creating simplistic “bathtub” models of sea-level rise, which are based primarily on coastal land elevation data, can be enormously effective in raising awareness of the potential impacts of sea-level rise. Such simple models, however, are not likely to be particularly informative for targeting specific on-the-ground management actions, since they don’t take into account important fine-scale processes, such as the effects of tides or sediment accretion. On the other hand, while conducting a more sophisticated and fine-scale analysis and assessment may require additional time and resources, it can ultimately produce a more actionable set of results for managers of specific places. Similarly, if your target audience is a federal or state agency developing an adaptation plan that aimed at conserving a particular endangered species, more complex assessments that consider detailed biological information about the species and involve projecting ecosystem-level changes to its habitat might be the most valuable approach if resources allow.

What Are Your Objectives?

Clearly establishing the goals and objectives is an essential step in designing a successful vulnerability assessment. First, consider relevant mandates, goals, and objectives that already exist for your organization, agency, refuge, or other such unit. Particularly for state and federal actors, these may constrain the degree of flexibility they have when it comes to the vulnerability assessment itself. However, how those goals and objectives are described is important from the standpoint of ensuring they are framed in ways that are clear and meaningful to those who will conduct the assessment. Consequently, the description of the goals and objectives should be a collaborative endeavor that includes the prospective end users as well as scientific and technical staff involved in carrying out the assessment. All too often, managers and researchers speak in different terms and have different expectations and understandings. Time spent at the beginning of a project to ensure that all participants have a common understanding of intended outcomes, technical requirements, resource needs, and timelines will maximize the likelihood of the assessment helping achieve the conservation goals. (See National Research Council [2009] for a detailed discussion of linking information producers and users.)

Ultimately, the purpose of conducting a vulnerability assessment in support of adaptation planning is to help increase the likelihood that you can achieve your conservation goals and objectives given the added impacts and complexities of climate change in conjunction with other stressors. The objective may be to restore and protect populations of a particular species or group of species. Or, it may be to ensure that a given ecosystem will continue to support sustainable levels of a natural resource such as timber, or provide certain ecosystem services such as clean water. In some cases, the goal may be to facilitate a substantial change in conditions, including changes in habitat and in the composition of plant and animal species, so that as much "naturalness" as possible can be maintained. Consider the vulnerability of your goal itself to climate change.

It will be important to get climate change adaptation principles embedded into established planning and decision-making processes.

Although vulnerability assessments can feed directly into stand-alone climate adaptation planning efforts, there will be other times when this information will need to inform existing agency and organizational planning or decision processes. Indeed, in many instances it will be more important to get climate change adaptation principles embedded into established planning and decision-making processes, many of which have the force of the law.

In some cases, the goals of a vulnerability assessment may depend on factors such as the management jurisdiction or mandate of the agency or agencies conducting the analysis. Many state wildlife agencies, for example, are focused on managing "species of greatest conservation need" (SGCN) as defined under their state wildlife action plans. While they may also be interested in assessing the vulnerability of habitats and ecosystems, targeting efforts toward those species will likely be important to inform the agency's relevant adaptation decisions. Federal agencies are required to utilize their programs in furtherance of achieving the conservation of species under the ESA. Some agencies or organizations may be responsible for managing a particular park or other protected area, or an area available for use for various purposes of high interest to the public—for them, regionally specific information about climate change will be of greatest interest and importance.

Regardless of the application and focus, coping with climate change will require fundamental shifts in the way conservation and natural resource management are carried out. The traditional approach of using past conditions and trends as a benchmark and goal for conservation will become increasingly problematic in a rapidly changing climate. While many of our conservation tools and principles will remain the same, it is likely that some of our goals and priorities will need to change as we look at protecting native species of fish, wildlife, and plants in a changing environment.

Gary Tischer/USFWS

Why Engage Stakeholders?

Engaging the right stakeholders in the right way and at the right times can be the critical factor in determining the success of an assessment under some circumstances. We address three important categories for decisions about stakeholder engagement in a climate change vulnerability assessment: why, who, and how. The goals and context of a particular assessment will, in turn, determine the kind and amount of effort directed to involve stakeholders.

First, consider what you hope to gain from stakeholder engagement. Engaging and informing stakeholders can help to accomplish the following:

1. Provide Data. While there is a large amount of relevant data available in public contexts such as on-line databases and the published literature, there are even more data available from less easily accessible sources such as site-specific monitoring programs or long-term citizen science projects. Less formal or accessible data sources can be particularly useful for understanding local or regional climatic or ecological systems and patterns and for providing information at a finer scale than is available elsewhere. For example, local observers and resource users can help to identify which particular climate variables (timing of first rainfall, minimum annual temperature, etc.) are likely to be most important for the ecosystem under consideration. The number and type of stakeholders that need to be engaged as providers of climatic or ecological information depends on various factors such as how well characterized is the system being assessed, the quality, size, and availability of existing data sets, and the degree of finer scale variation within the system.

2. Refine Scope and Focus. To maximize the usefulness of a vulnerability assessment, it is also important to engage stakeholders in determining the scope or focus of the assessment. If the goal is to inform resource management over a wide area involving multiple jurisdictions, for instance, you need the input of a broad array of resource managers as to how they make decisions—the timing of decision cycles, the variables they use, etc. Defining the scope or focus may happen in two stages. A smaller group of individuals may conduct an exploratory vulnerability assessment that is used to inform decisions about who needs to be engaged at a broader level. Again, the approach taken will depend on the specific circumstances.

3. Provide Sociopolitical Context. Because the sociopolitical setting influences the climate vulnerability of natural systems, it is important to engage stakeholders who can explain and integrate important components of the sociopolitical system into the assessment. These components may include national, regional, or local laws, regulations, rules, and plans; important subsistence or cultural uses of the natural environment; and value systems that may determine how human systems in the region in question respond to climate change. While ecological and sociopolitical elements of vulnerability are often considered separately, some level of integration is likely to produce more robust and useful results. Local stakeholder engagement is especially important when there are ethnographic considerations. Cultural and/or spiritual information is often poorly documented or resides entirely in oral histories and traditions.

4. Build Support for Adaptation. Finally, if the goal is to use the vulnerability assessment for climate change adaptation planning, it is worth engaging individuals and organizations that will be important for developing and implementing the adaptation plan (Vogel et al. 2007). They may not need to be full participants in the vulnerability assessment, but they may need to know that it is happening and understand how it will feed into the adaptation planning process. This is particularly relevant if one's goal is to support adaptive management plans that accompany or are part of climate change adaptation plans or other conservation plans, since such plans may require broad public support to achieve the needed level of flexibility.

Box 2.4. Steps to Identify the Appropriate Scope of Stakeholder Participation

- Create an initial list of organizations, interest groups, and individuals who may wish to be involved in the process or whose buy-in may contribute to project success or failure.
- Meet with representatives of these groups separately in informal settings that are familiar to the people with whom you are meeting.
- Explain clearly the principles of vulnerability assessment and adaptation and the goals of the project with which you are asking them to engage.
- Emphasize the importance of public participation, and that you are asking them to decide among a range of options for engagement, both in terms of the level of involvement and the mechanism.
- Ask group members to express their interests or concerns, and request the selection of a group representative to participate in an initial joint meeting of all the groups.
- Ask these interested parties if they know of others who should be involved in the process.
- Once all interested groups, sectors, and individuals have been approached individually, hold an initial meeting with representatives from all interested groups and sectors to agree on the details of the participation process. Depending on funding and the degree of trust among participants, it may be useful for participants to select a mediator for the stakeholder engagement process, someone who is widely respected and viewed as neutral. It may also be necessary to provide some background information or training for stakeholder groups, for instance if they will be asked to interpret the results of climate models.

Source: Integrated Resource Planning Committee (1993).

Whom to Engage?

The variety of individuals and organizations that may need to be involved is as great as the variety of reasons to engage them at all. Categories to consider include:

- Decision-makers (e.g., regulators and managers), in addition to those who may be requesting or directing that a vulnerability assessment be conducted

- Decision implementers (e.g., managers)

- End users of resources/lands (e.g., hunters, birders, oil and gas developers)

- Opinion leaders (influential and respected individuals within the region or sector of interest)

- Climate change adaptation planners

- Providers of information (e.g., scientists, holders of traditional knowledge, sociologists, etc.; will usually overlap with other groups)

Time allocated to thoughtfully identifying and engaging stakeholders in the vulnerability assessment will usually be more than worth the effort if the vulnerability assessment is to be part of a longer-term engagement on climate change issues.

How to Engage Stakeholders?

The degree of stakeholder engagement in a vulnerability assessment may vary widely. At one end of the spectrum, it may involve simply providing information along the way, while at the other end of the spectrum it can involve guiding the entire process. It is generally the case that the more deeply engaged stakeholders are, the more committed they will be to a climate change vulnerability assessment and to using the results in subsequent adaptation planning and projects. The expected scale of the assessment and of the subsequent adaptation planning will help determine the most desirable level of involvement by specific stakeholders. Engaging too many stakeholders or engaging stakeholders too intimately can lead to a quagmire in which little is accomplished; engaging too few stakeholders or engaging stakeholders too shallowly can lead to inaccurate or incomplete assessments and lack of buy-in for subsequent adaptation projects.

The more deeply engaged stakeholders are, the more committed they will be to using the results.

One important element of engaging stakeholders is to be clear with them about their role. This may vary depending on the circumstances and on the stakeholders involved (e.g., in some circumstances you may want the selection of assessment targets to be determined entirely or largely by stakeholders, while in other circumstances the selection of targets may be dictated by the organization or agency conducting or commissioning the assessment).

Another important element is to let stakeholders know about any decisions that already have been made about assessment targets and processes. For example, there may be situations in which resource managers identify target species or habitats for climate change vulnerability assessments due to legal or policy considerations, and that while stakeholders may be asked for input about additional species to assess, some targets may be set *a priori.*

Finally, it is important to acknowledge the value of stakeholders' time and offer constructive ways to ensure that both you and they benefit from their engagement in the assessment process.

Selecting Assessment Targets

Species

Given that a significant portion of the conservation work at the state and federal levels are focused on individual species of plants and animals, species are and will likely continue to be one of the primary targets for climate change vulnerability assessments. A wide variety of traits and processes can make a species more or less vulnerable to climate change. The effects of a changing climate tend to exacerbate the effects of other threats, such as habitat loss or pressure from invasive species that may have already made a species susceptible to population declines or even extinction.

The World Conservation Union (IUCN) has described five categories of biological traits that can make species more vulnerable to climate change (Foden et al. 2008):

- Specialized habitat or microhabitat requirements

- Narrow environmental tolerances or thresholds that are likely to be exceeded under climate change

- Dependence on specific environmental triggers or cues that are likely to be disrupted by climate change (phenological responses—e.g., rainfall or temperature cues for migration, breeding, or hibernation)

- Dependence on interactions between species that are likely to be disrupted

- Inability or poor ability to disperse quickly or to colonize a new, more suitable range

Target species may be selected for a wide array of reasons. Some species may not have any of the biological traits that match the list above, but an assessment of their vulnerability to climate change may be of interest for other reasons. For example, the vulnerability of species that are of high economic, social, or cultural value in an area may be of interest to resource managers, business people, and others who want projections to help them gauge whether regional populations are likely to be sustained or to move elsewhere as a result of a changing climate, even though they are not at risk of becoming extinct. The first three case studies in Chapter VII are examples of climate change vulnerability assessments targeted to species.

Habitats

As described earlier, the term habitat is used in a variety of ways. Nonetheless, because many wildlife conservation actions are delivered on the ground based on a habitat framework, using habitats as the target of a vulnerability assessment can be a helpful way to ensure that the results will support the needs of managers. Focusing on specific habitats as a target for vulnerability assessments may occur as an objective in and of itself, or may be in tandem with efforts to assess species vulnerability.

Climate change can affect habitats in a number of ways (e.g., it can alter their species composition, their location and/or their size, or their functioning). For example, areas that are currently managed as important shrub–steppe habitat may become more suitable for piñon–juniper habitat or may be likely to undergo changes due to fire and invasive species under future climate conditions. Further analysis (both quantitative and qualitative) can help determine how these habitat changes might affect associated species, such as greater sage-grouse, various species of migratory songbirds, and numerous other animals and plants associated with shrub–steppe habitat.

As with species analysis, climate change vulnerability assessments for habitats can range in levels of complexity. There are a number of modeling tools and resources that can assist habitat managers in conducting vulnerability studies. For terrestrial systems, scientists frequently rely on models that can project shifts in the range of vegetation or other organisms due to changes in climatic variables, usually at relatively large regional scales. Some of the more basic models project vegetation changes under steady-state conditions. Specifically, they relate the current distribution of a species to current climate conditions, such as temperature and precipitation, and then project a potential future range under scenarios of future climate conditions (Botkin et al. 2007). It is also possible to apply more complex models that can simulate habitat responses and project potential changes in ecosystem structure and function.

For aquatic habitats, wider availability of spatially and temporally downscaled climate models have allowed for more localized projections on likely changes in temperatures and precipitation to a scale relevant for hydrological impact studies, which can help inform watershed planning and other management efforts under climate change (Wood et al. 2004).

Ecosystems

The use of ecosystems as the basis for climate change vulnerability assessment will depend largely on the availability of ecological characterization and mapping efforts in the region of concern, and on the way in which ecosystems (or related concepts) fit into prevailing management and planning regimes. Some assessments may focus entirely on a single large-landscape "ecosystem," in which case the assessment targets will not actually be the ecosystem itself, but rather subcomponents such as species or particular biological communities or habitats, or an examination of ecological processes.

Of particular concern in assessing ecosystem vulnerabilities are the potential for disruptions in ecological interactions and compromises to key ecosystem functions and processes (Shaver et al. 2000). In turn, impacts to ecosystem functions can have profound consequences for the services that are provided by the particular system. The concept of ecosystem services (e.g., water production, carbon sequestration) increasingly is serving as an important framework for human valuation of natural systems (Millennium Ecosystem Assessment 2005). Because many ecological assemblages (e.g., the connection between pollinators and the flowers they fertilize, or breeding birds and the insects on which they feed) will likely be disassembled under future climate change as their component species respond to changes differently, a combined strategy of targeting both species and ecosystems may be desirable in many situations (Root and Schneider 2002).

Further complicating matters is the fact that the ecological impacts of climate change do not occur in isolation, but combine with and exacerbate other stresses on our natural systems. Leading threats to biodiversity include habitat destruction, alteration of key ecological processes such as fire, the spread of harmful invasive species, and the emergence of new pathogens and diseases. The health and resilience of many of our species and natural systems are already seriously compromised by these "traditional" stressors and changes in climate will have the effect of increasing their impact, often in unpredictable ways. As noted earlier in this document, some aspects of sensitivity, exposure, and adaptive capacity take other stressors into account to some degree. For some systems and situations (again, depending on users' needs), it may be important to take an assessment approach that more specifically integrates the intersecting effects of all the important stressors.

Although assessing the vulnerability of ecosystems to climate change is inherently complex, advances in modeling have made such assessments more accessible. For example, some dynamic global vegetation models (DGVM) can simulate ecosystem processes such as carbon dioxide (CO_2) uptake and fluxes in nutrients and water (Bachelet et al. 2001).

Chapter IV provides more detail about the use of these and other models in conducting a climate change vulnerability assessment for species, habitats, and ecosystems.

Space and Time: Selecting the Right Scales

Setting the appropriate geographic scale for your vulnerability assessment and determining over what time scale the analysis should cover are two key factors in designing a successful assessment.

Geographic Extent

Climate change vulnerability assessments can be done at local, regional, and national scales. As with the identification of the relevant assessment targets, a number of factors can determine the spatial scale on which you will focus. By its very nature, however, climate change will require that we think and plan within the context of larger landscapes, even when our management needs are very local. For example, many species are expected to shift ranges in response to shifting climates,

An inverse relationship exists between the geographic scale of an assessment and the certainty of projections.

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and as a result, our existing portfolio of protected areas and wildlife management areas may no longer support the suite of species for which they had originally been established (Hannah et al. 2007). This is especially true for migratory species, whose habitat range may span several states, countries, or even continents. Accordingly, selecting an appropriate geographic scale for an assessment must consider not only the organization's management jurisdiction, but also the geographic requirements of the species or ecosystems that are the target of the assessment.

Clearly defining the spatial scale of the assessment early can help keep the process as efficient as possible. If an assessment is conducted at the state level, it is important to consider how it will take into account species that cross state boundaries, including species that may move into or out of the state or region under future climate conditions. In some cases, conducting a multi-state vulnerability assessment or coordinating with neighboring states can help resolve these problems (see, for example, Case Studies 6 and 7).

Much adaptation planning and implementation will, of necessity, be conducted at the level of individual land management units, whether parks, preserves, military installations, national forests, or other managed landscapes. Ideally, such local-scale planning will be able to draw from vulnerability assessments conducted at broader geographic scales. Nonetheless, some local-scale managers will be interested in conducting their own vulnerability assessments. To the extent possible, these should be structured to build from and take advantage of assessments covering the state or multi-state region in which the landscape rests.

Vulnerability assessments for individual protected areas should identify the likely effectiveness of those areas to support a given species, habitat, or ecosystem under scenarios of climate change. Beyond considering the species or habitats that may be lost from an area, however, they should consider what species or habitats may be likely to move into the area that may be of management interest. In general, it is important to consider the scale of projections from climate models and the scales desired for projections of biological responses, to ensure they match appropriately (Wiens and Bachelet 2009). There is often an inverse relationship between the geographic scale of an assessment and the level of certainty regarding projections of both climate and ecological response. Climate projections, for instance, are most robust at coarser scales, and even with the availability of downscaled climate projections, less so at finer scales. As a result, in carrying out vulnerability assessments at local scales, it is particularly important to understand uncertainties and refrain from overinterpreting fine-scale projections.

Time Frame

Another key consideration is which climate change scenarios to use, and over what time frame. As described in detail in Chapter IV, there are multiple scenarios available based on a range of assumptions, including future emissions trends, levels of economic activity, and other factors. Identifying the potential impacts of climate change under multiple scenarios and time steps (e.g., 10 years, 25 years, 100 years) will be important to inform a range of possible management strategies. In determining the appropriate time frame for an assessment, consider that near-term projections of climate change scenarios tend to have a higher degree of certainty than those that look farther out. This is the case because it is difficult to anticipate how greenhouse gas emissions might change in the future, whereas the climate change we experience over the next few decades will be primarily caused by past emissions. However, it may be appropriate for some vulnerability assessments to consider a longer time frame, acknowledging the higher level of uncertainty in long-term climate projections.

Complexity: More Isn't Always Better

Climate change vulnerability assessments for species and ecosystems use a range of methodologies, from qualitative assessments based on expert knowledge to highly detailed, quantitative analysis using ecological models. Selecting an approach may depend on a host of factors, including the availability of already existing information, the level of expertise, time and budget constraints, and so on. For example, while there are a growing number of models available that can project the impacts of climate change on plant and animal ranges, the availability to conduct more detailed analyses such as modeling the dynamic ecological responses among diverse species within and among ecosystems is still relatively limited. In some cases, focusing quantitative assessments more broadly on habitat changes and then applying qualitative assessments of potential species responses may be the best approach given existing information. Additional studies can then be undertaken as information and resources allow.

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Embracing Uncertainty

Assessing the vulnerability of species, habitats, or ecosystems to most stressors, and certainly to climate change, is complex, and there are different levels of certainty and confidence in each piece of scientific information and expert knowledge that are integrated together to produce a vulnerability assessment. Uncertainty is a reality: No one knows exactly how climate may change or how ecological or human systems may respond to change, in any particular location.

Management decisions can proceed in the face of uncertainty. A useful way to characterize uncertainty in the assessment process is the level of confidence in a given input or outcome. In some instances we will have a high level of confidence in some or all of the parts determining climate change vulnerability, and in other cases we may be less certain in one or more vulnerability factors. It is important to understand the level of certainty about the different components of vulnerability, to identify the range of potential vulnerability given the uncertainties, and to determine what we can and cannot say about the vulnerability of the system. At the same time, lingering uncertainty about climate change need not paralyze us in making decisions and developing strategies for adapting to climate change. Chapter V provides a more detailed discussion of the nature of uncertainty, presents a language for addressing certainties and uncertainties, and provides methods for incorporating uncertainty into vulnerability assessments.