CHAPTER 1

A New Era for Ecologists

INCORPORATING CLIMATE CHANGE INTO NATURAL RESOURCE MANAGEMENT

Kimberly R. Hall

RAPID CLIMATE CHANGE IS one of the most pressing challenges facing resource managers and conservation practitioners in California and around the globe. Since the 1880s, the linear trend in average global surface temperature suggests an increase of approximately 0.85°C in the Northern Hemisphere, and the last 30 years were likely the warmest period in the last 1400 years (IPCC 2013[AQ1]). It is critical that we accelerate efforts to reduce the accumulation of greenhouse gases in our atmosphere (mitigate the causes of climate change). However, even if drastic reductions are achieved, the emissions that have already been released through the burning of fossil fuels, compounded by the loss of forests and other natural systems that store carbon, commit us to continued changes in climate for many decades to come (Solomon et al. 2009). The rapid pace of changes, combined with the complexity of potential responses of species and natural systems to different climatic factors, suggests that we will often need to transform, rather than just update, our management approaches (Kates et al. 2012, Park et al. 2012). The extent to which ecologists in the research, conservation, and management fields are able to contribute viable strategies to address these challenges, and promote transformation in our approaches to management, has important implications for biodiversity, natural systems, and the ecological services that support all species, including humans.

AQ1: Reference 'IPCC 2013' is not included in the list of Literature cited. Please provide the reference details to be included in the list.

The goals of this book are to help motivate efforts to reduce greenhouse gas emissions by describing observed and likely vulnerabilities of species and natural systems to climate change, and to help accelerate the pace of climate change adaptation in the natural resource management sector. The focus of this chapter is on framing how scientists and managers can work together to design and implement updates to our management and conservation practices that increase the odds that species and systems adapt to climate change. While most of the chapters in this book focus on observed impacts in California ecosystems, here we emphasize adaptation, and provide an introduction to the frameworks and tools available in the emerging field of adaptation planning. These frameworks and tools provide the pathway forward for incorporating what we learn from the study of responses of species and systems to climate change into natural resource management and conservation strategies.

Steps for adaptation planning include identifying likely changes in key climatic factors, characterizing the risks that these changes pose to things we care about, prioritizing those risks, evaluating the consequences of various strategies to reduce risk, implementing preferred actions, and tracking and learning from these actions (Moser and Ekstrom 2010, Poiani et al. 2011, Cross et al. 2012, Stein et al. 2014). While science is a critical input to these tasks, it is not by itself sufficient (Gregory et al. 2006), and lack of information should not be used to delay action. Given that the need for "more science" is often described by practitioners as a barrier to adaptation (Heller and Zavaleta 2009, Moser and Ekstrom 2010, Bierbaum et al. 2013, Petersen et al. 2013), a key step that scientists, managers, and policy-makers can partner on is reminding each other that we make decisions under uncertainty all of the time, and there are methods we can use to help make these decisions more rigorous and more transparent. In addition to investing in more science, to make progress on adaptation, we need to think more broadly about the skills and processes that can facilitate society's ability to act on what we observe, and plan for the changes that our climate and ecological models suggest are likely to occur.

Making decisions on how to address climate change risks to species, natural systems, and the people that depend on these systems requires that we integrate science with information on societal values and account for many types of uncertainties (Schneider et al. 2007, National Research Council 2009). Integration of science with values and the collaborative determination of likely costs and benefits of various adaptation actions require that science be presented clearly, with key thresholds identified where possible. As ecologists, we need to explain the logic behind our expectations for the future, and explain our assumptions in ways that help nonscientists understand the relationship between various climate drivers and the sensitivities of species and systems. When we are able to communicate science clearly, we can play an essential role in promoting science-based decisions: We enable a broader group of stakeholders to act as partners in the evaluation of the risks, costs, and benefits associated with different actions (Gregory et al. 2006, Schneider et al. 2007, National Research Council 2009, Moser and Ekstrom 2010). While the myriad of uncertainties associated with climate change impacts (and human responses to these impacts) present a major challenge, tools and frameworks for handling uncertainty continue to grow (National Research Council 2009, Kujala et al. 2013, Hoffman et al. 2014). For those of us trained in the natural sciences, uncertainty and complexity are not new concerns, and learning new ways to handle these elements will likely make us better scientists.

Although learning about tools for handling uncertainty is important, actually engaging in the process of identifying management options that could promote adaptation, and framing out the costs and benefits of those options will likely provide insights that can only be gained through this experience. One lesson that is likely to emerge is that not all "unknowns" that could be addressed with new scientific research are equally relevant (Hoffman et al. 2014). Processes like structured decision-making are particularly suited for helping illustrate this point (e.g., Keeney 2004, Martin et al. 2009), but this honing in on a smaller set of critical uncertainties will likely occur in most situations where policy-makers and managers are working through a management strategy decision, updating management goals, or re-prioritizing investments. Given the urgency of addressing climate change risks, our goal should be to emphasize research into the uncertainties that have the most influence in terms of helping us choose the best options for protecting the things we value. When "decision-critical" science is identified during the process of choosing among alternative management actions, scientists engaged in the process can greatly enhance the decision-relevance of their work by developing new projects that target these uncertainties (Martin et al. 2009, Mastrandrea et al. 2010). This type of partnership has the added benefit to researchers of providing a ready audience and application for their work, which can greatly improve the likelihood of support from funders, and promote interest in and critical feedback on the work from stakeholders. In California, there are many entry points for engagement, such as through workgroups for the California Climate Change Assessment process, or through contributions to the adaptation strategy (information available at the California Climate Change Portal, www.climatechange.ca.gov).

A main barrier to successful partnerships among scientists, managers, stakeholders, and decision-makers is lack of communication. While strong communication skills are often recognized as being essential for creating and maintaining partnerships, few academic scientists have direct opportunities to build the full complement of needed skills. These skills go far beyond writing an article for a broad audience, or being able to give a presentation describing one's work without jargon. We also need to be able to listen and ask questions, so that through dialogue we can identify information gaps, misunderstandings, and understand the bounds of the problem to be solved. One way for students in the sciences to build these skills and build relationships that promote long-term engagement in management decisions is for them to take advantage of opportunities to learn from managers. Ideally, these managers would be addressing questions that could potentially be informed by their area of research, but there is much to be learned even if this is not the case. While textbooks and journal articles may promote particular management actions or conservation strategies, direct engagement with decision-makers who are working toward a particular set of management objectives can provide critical insight into how scientific information is integrated with information on societal values, and social, technological and financial constraints.

This book represents one example of graduate and postdoctoral researchers taking steps to make these connections with resource managers and conservation practitioners. As noted in the Preface, encouraging students to engage with researchers was the focus of the project funded by the California Energy Commission through the Public Interest Energy Research (PIER) program. The four editors of this book served as mentors in the project, which we called Biological Impacts of Climate Change in California (BICCCA). Our goal was to give graduate and postgraduate students at California universities encouragement and opportunities to meet and engage with on-the-ground resource managers and conservation practitioners, and to work with them to improve their oral and written communication skills. All chapters in this book were written to be accessible and relevant to both applied and academic audiences. Further, many of the chapters are accompanied by "conversations" between students in the BICCCA program and practitioners responsible for managing ecological systems under climate change. Though these conversations only scratch the surface of topics that long-term collaborations to sustain biodiversity will need to address, they demonstrate some of the key opportunities and constraints that arise as scientists and managers work more closely together. Our hope is that as students, established academic scientists, and natural resource professionals read these chapters, they will be inspired to initiate or increase their engagement in similar conversations.

RESPONDING TO CLIMATE CHANGE: A CALL FOR STRONGER COLLABORATIONS

Our desire to help "bridge the gap" between science and practice in the context of updating resource management is driven by the magnitude of climate-related risks to biodiversity. The bridges we construct are likely to be most stable if we recognize that fundamental assumptions underlying how we think about nature have changed. Most are likely to agree with the idea that "stationarity is dead" (Milly et al. 2008); we can no longer make decisions about resource management with an expectation that patterns of variation in climate-sensitive systems will stay within historic ranges. But how do we think through what might happen over the next decade, or next century? Practitioners often establish "desired future conditions" for a site based on a historic reference condition, or try to achieve a changing mosaic of ecological site conditions that would have occurred under historic ranges of variability. However, as we move away from the assumption of climate stationarity, we need to reconsider what it is we are managing toward. This is one of the many ways the challenge of responding to climate change requires that we change our way of thinking, and stretch our imaginations, as much as it calls us to action.

Until we achieve stabilization of greenhouse gas concentrations, we face a future of continued change. This unfortunate reality suggests we should design resource management plans that are flexible enough to account for continued change over time, which explicitly address multiple forms of uncertainty, and likely increases in the frequency of many types of extreme climate events. One challenge to overcome as we work toward these goals is that traditional scientific and management approaches are not well suited to helping us prepare for directional change, variation across space and time, and extremes. Historically, ecological research has focused on simplified model systems in which we can rigorously test hypotheses, which has also meant that work is typically carried out on small focal areas or study plots, with a focus on relatively narrow ranges of variation in one or a few environmental variables. Similarly, this type of training is likely to have framed the perspectives of practitioners, and shapes the monitoring and other tools we use to inform our work. Depending on our experiences thus far in terms of observed ecological responses, this lack of points of reference for thinking about change can be a key barrier to conceptualization of how to move forward.

Our challenges in addressing change and variation highlight another tendency of the resource management / conservation practitioner community, of which three of the four editors of this book are a part. Recent research suggests that practitioners tend to be risk averse with respect to investing in actions perceived as risky, untested, or outside of the norm (West et al. 2009, Hagerman and Satterfield 2013). While we often claim to be engaged in an adaptive management approach, suggesting that our management actions are embedded in a study design that allows the comparison of different options through targeted monitoring, our visions for implementing adaptive management are often not well supported by available resources. The degree to which managers promote different types of adaptation actions may be influenced by both scientific support for the premise underlying the specific action and the degree to which it represents a digression from past activities (West et al. 2009). For practitioners, there is the added challenge of deciding how much to invest in addressing climate-related risks, given that other stressors such as habitat loss, pollution, or impacts of invasive species often seem more pressing (Lawler 2009, Hagerman and Satterfield 2014). We may also have greater confidence that scarce resources will actually do more good if spent on these time-tested approaches (West et al. 2012), rather than on risky new ideas. Further, we may feel overwhelmed by the idea of being responsible for unintended consequences following the application of a novel approach (Hagerman and Satterfield 2013, Hagerman and Satterfield 2014). Thus, in addition to developing modes of research that are a better fit to the challenges we need to address, a second key role for scientists may be developing explicit strategies for dealing with this bias toward the familiar. With respect to the knowledge and certainty thresholds that need to be attained to support implementation of adaptation actions "the burden of truth is much higher for unconventional actions" (Hagerman and Satterfield 2013, p.561), suggesting that working with practitioners, to first frame potential benefits and risks and second evaluate innovative actions when they are chosen, is a critical need.

As we frame risks and benefits, an approach that considers multiple lines of evidence should help us anticipate a broader range of species and system responses. Different fields of study, from investigations of genetics, through population dynamics, to landscape ecology, provide different lines of questioning and different ways of exploring responses. In some cases, looking at a problem through a different lens may suggest fewer uncertainties regarding a plan of action, while in other cases bringing in new tools and frameworks may open up even more questions. As a mentor in the BICCCA program, I saw the diversity of scientific disciplines and perspectives represented by the students and mentors as our greatest strength. Focal ecological systems for students in the program ranged from marine systems (Chapters 4 and 5) through rivers (Chapter 6), alpine systems (Chapters 7 and 8), and grasslands (Chapters 9 and 10). The collection of work here employed a wide range of tools and approaches, addressed many different taxonomic groups, and spans temporal scales from a few years for most work through decades (Chapter 8 and 13) and even millennia (Chapter 12). Given the complexity of the relationships between species life histories and climate drivers, we should expect that we will need multiple approaches to help answer our questions on how to help systems adapt. By drawing from many lines of evidence, we can likely better anticipate a broader spectrum of species and system responses, and more effectively work through processes that allow us to compare risks and prioritize management actions that most effectively reduce these risks. As this idea suggests, there is often a need to bridge across different fields within the biological sciences, again emphasizing the need for clear communication skills, and a commitment to engaging in processes that promote cross-disciplinary learning.

Operationalizing adaptation

Most resource managers, especially in California where a wide range of climate-related responses have been observed and projected (e.g., McLaughlin et al. 2002, Kelly and Goulden 2008, Loarie et al. 2008, Stralberg et al. 2011), are likely to agree that climate change presents a key stressor to ecological systems and the services they provide. The chapters in this book add numerous examples that help shape and expand our understanding of vulnerable species and systems. However, even when we recognize the threat of climate change, steps to reduce risks can be hard to identify. The complexity inherent in understanding what climate changes are likely and predicting ecological impacts are likely key contributors to climate change being addressed "more than before, but less than needed" (Bierbaum et al. 2013) in the natural resources management / conservation sector. Long before climate change emerged as a conservation game changer, managing and protecting biodiversity given all of the other stressors that drive species declines represented a daunting task. As before, our work is tightly constrained by costs, and at times is in conflict with other stakeholder values. The interviews with resource managers that accompany many chapters give voice to these barriers to implementation of adaptation actions.

Designing and updating management approaches in ways that allow us to reach our project goals as climatic conditions change requires that most, if not all, resource managers move past these barriers and get into the habit of "asking the climate change question." Some may feel they are not prepared to take on this role. However, local knowledge on the ecology, management practices, site history, and social opportunities and constraints represent critical areas of expertise in this process—no "climate adaptation specialist" can step in and reduce the need for this knowledge. Updating management to account for climate change requires that we integrate this site-specific information with information on how changes in climatic drivers are likely to influence species and systems. Ideally, this integration will occur through a long-term partnership between climate specialists, ecological researchers, and practitioners. Integration may take many forms, and how to get started will depend on who is sitting at the table. How we go about integrating climate change is also likely to change over time: While investing time in planning efforts that focus solely on climate impacts and adaptation can play an important initial role in helping stakeholders get up to speed on new ways of thinking, over the long-term adaptation actions are more likely to be implemented if they are part of ongoing planning and management cycles. While integrating climate change into all decisions may seem overwhelming, this idea of repeatedly "asking the climate question" reminds us that we will have many opportunities to promote adaptation, and we can (and must) learn as we go.

While there is no one-size-fits-all answer on how to modify management to address climate change, or even one set of climate change questions that are appropriate for all situations, one way to help train ourselves to make adjustments is to follow a consistent, systematic process as we get started. A shared process, and shared tools, can also help different stakeholders work together by clarifying ideas on impacts and assumptions that underlie any proposed changes in goals or plans for action. Efforts to promote adaptation to key stakeholder groups have been rapidly increasing: Guidance documents, tools, workshops, and websites are being developed at all levels of government, in nongovernmental organizations, and in the private sector (Bierbaum et al. 2013). Within the conservation and resource management literature, there are many sources of recommendations and general principles for how to help natural systems adapt (e.g., AFWA 2009, Joyce et al. 2009, West et al. 2009, Hobbs et al. 2010, Lawler et al. 2010, Hansen and Hoffman 2011, Poiani et al. 2011, Cross et al. 2012, Stein et al. 2014). Like the specific strategies needed to reduce climate-related risks in a given geography, the guidance, tools, and information that will be most useful in helping stakeholders move forward on adaptation will likely vary from place to place.

To provide context for how information in the rest of this book can be applied, we present a slightly modified version of an approach used by The Nature Conservancy (TNC) to update existing conservation plans (Poiani et al. 2011). This approach assumes that a team of scientists, managers, and policy specialists has already gone through the process of creating, and likely implementing, a conservation plan designed to protect species, systems, and / or ecological processes at a specific location. When presented in a general way, this framework's focus on updating an existing plan, which typically includes multiple conservation objectives, and strategies for addressing a wide range of stressors (i.e., invasive species, pollution, habitat loss or fragmentation) may be a good fit for others interested in sequentially reconsidering how to increase the likelihood of success of actions taken within an ongoing management or conservation effort. In addition, we like the fact that this framework includes the step of considering human responses to climate change as an additional challenge, and that it highlights the idea of looking for opportunities to demonstrate how protecting nature can protect people. When this framework is followed at a more detailed level, familiarity with TNC's conservation planning approach is helpful, which may require more of a time investment than makes sense for practitioners that use other planning approaches. This is one example of why exploring the range of adaptation frameworks and tools available before selecting methods to follow, especially if one is organizing a major effort with multiple partners, is a good idea. For example, for those that are engaged in new efforts, such as an emerging partnership to address climate change impacts in a place where goals and strategies have not already been created, broader frameworks with more flexible approaches may be more helpful (e.g., Hansen and Hoffman 2011, Cross et al. 2012, Stein et al. 2014). However, there are many similarities in steps for different processes, so while the TNC approach (Poiani et al. 2011) was developed for a specific mode of application, it still serves well as a method for connecting information from later chapters to a general process for updating conservation and management.

STEP 1. UNDERSTAND THE POTENTIAL ECOLOGICAL IMPACTS OF CLIMATE CHANGE This step involves gathering information on observed and projected climatic changes, and linking these to potential sensitivities in the focal ecological systems, species, and management actions. As noted above, the step of understanding vulnerabilities is most efficient, and likely most effective, when information such as temperature-change projections is connected to local sensitivities through active discussions, rather than through more passive transfers of information from scientists to managers. When climate scientists, ecologists, managers, and others familiar with the focal species or system work together, they can explore and eventually refine ideas about the specific aspects of some kind of change that is most relevant for considering specific risks. We might have a sense that a species is sensitive to temperature, but there are many ways that temperature can change, leading to different levels of exposure and different risks. For some species, the most meaningful climate data metric might be summer maximum temperatures, as these may correlate with heat-related mortality. Perhaps less intuitively, others may be most at risk from increases in winter low temperatures, which may have in the past limited the spread of an important pathogen or invasive species. Or, maybe the strongest influence of temperature increases is through a less direct driver, such as length of the growing season, increase in stream temperature, drought stress, or timing of snowmelt. In many cases, multiple mechanisms are likely, and they may act in the same direction (i.e., suggesting increasing risk), or may suggest both risks and benefits.

Once useful metrics are identified, ecologists and practitioners can work with climate scientists to identify the best climate data sources for evaluating changes in the metrics over time. Given the many sources and methods for downscaling climate data, and the rapid increases in availability of these data (Barsugli et al. 2013), spending some time thinking critically about what data are most useful before trying to retrieve them should lead to more productive conversations with climate scientists. Other important components of this step include identifying one or more workable time frames for considering impacts (e.g., 20 years, or a short- and long-term reference point), identifying ways to handle the variation across different emissions scenarios and models, and framing some form of conceptual model to help with the identification of likely impacts. While described very briefly here, this step is essentially a climate change vulnerability analysis, and can be undertaken at many different levels of investment. A more detailed description is beyond the scope of this chapter, but many resources and tools are available to help with this process (e.g., Glick et al. 2011, Klausmeyer et al. 2011, Rowland et al. 2011, Thomas et al. 2011, Gardali et al. 2012, Wilsey et al. 2013).

A key point to recognize when working with climate specialists to identify which changes in climate drivers are most important is that these changes can affect many aspects of management. Thus, besides thinking about how changes in factors like the timing of spring, or peak water temperatures, may put species at risk, it's important to also consider how changing conditions can change the effectiveness of some form of management action, or change the influence of neighboring land uses on a focal property. For example, too much or too little moisture can restrict use of tools like prescribed burning, which may reduce a manager's ability to control invasive species. Changes in climate factors may lead to new problems with existing infrastructure, such as reduced stream connectivity due to perching of culverts in road-stream crossings during times of high drought stress / low stream flow. Similarly, paved areas in a neighboring parcel may be more likely to contribute to flooding as storm intensities increase, which can promote overland flow and erosion that leads to degradation of the nearby aquatic systems.

In these conversations, we should also consider the potential for "surprises" (Root and Schneider 2006) of at least three forms: (1) Exceedance of thresholds in some kind of response to climatic changes (e.g., if conditions exceed key thermal or drought tolerances, this may lead to rapid, hard-to-predict declines in fitness); (2) new interactions among species, and / or new or synergistic impacts related to interactions with climate and other stressors (e.g., climate change favoring an invasive species that had not been able to become established in the past); and (3) higher frequency of extreme weather events with catastrophic impacts on focal systems or management infrastructure (floods, ice storms, extreme cold periods in spring). Through interactive discussions, and by testing different ideas over time, scientists familiar with the climate data and managers most familiar with the systems can hone in on climate metrics that best inform consideration of risks. We hope that this book helps encourage these interactions and provides useful information and examples that help move the process along.

STEP 2. FORMULATE SPECIFIC "HYPOTHESES OF CHANGE" After engaging in a broad consideration of possible impacts, the next step in the TNC framework (Poiani et al. 2011) involves focusing in on a set of important ways in which climate change might impact a species, system, or management strategy. The step of creating "hypotheses of change" can help tame the complexity of the adaptation process by asking participants to craft statements that describe specific, management-relevant shifts in focal systems or species. For example, in the multi-team workshop described by Poiani et al. (2011, p.189), the Moses Coulee project team from Washington state developed the following statement:

> A 2–3°C rise in annual temperature coupled with a 10–30% decrease in summer rainfall and a 5–10% increase in winter precipitation will lead to a greater frequency and intensity of wildfires, which create openings for expansion of invasive cheatgrass, and increased spring productivity of cheatgrass, resulting in the decreased cover of key native shrubs and bunchgrasses.

Generating lists of possible changes and linking them in a conceptual model can help organize a group's thinking, making it easier to identify a subset of vulnerabilities that can potentially be reduced through management actions. The premise here is that each hypothesis of change should be specific, and should illustrate clearly the connection between one or more specific climate drivers and a change in our ability to meet some conservation objectives. Clearly stating these relationships helps ensure that we "link actions to climate impacts" as we develop adaptation strategies, one of the "key characteristics to climate-smart conservation" identified in comprehensive guidance from Stein et al. (2014, p.38). Ideally, each of these statements would also be associated with some descriptor of how likely the impact is (high-medium-low probability). When combined with factors such as the magnitude of the impact and its reversibility, the likelihood can help identify which risks are of highest priority for being addressed with adaptation actions.

STEP 3. EXPLORE POTENTIAL SOCIETAL RESPONSES TO CLIMATE CHANGE Many, if not most, of the ecosystem stressors addressed through management are strongly tied to human actions, such as land conversion, pollution, and introduction of nonnative species. Thus, part of updating our approach to include climate stressors in management involves thinking about the responses of people to climate change, as these will likely contribute to changes in stressors, and in future management priorities. The goal of this step is to anticipate, and where possible prevent, responses that could cause more problems for ecosystems. In some cases, this step may lead to work on quantifying the ecological services that current natural systems are providing, or that could be provided through restoration, which help reduce climate-related risks. Examples include investing more of our resources into protecting forests to maintain sources of freshwater, and protecting or restoring floodplains to help contain spring floods (Kousky 2010, Downing et al. 2013, Gartner et al., 2013). By proactively thinking about societal responses, we can hopefully identify and communicate ways that natural areas help promote adaptation for people, and anticipate and help avoid actions taken to protect people that could damage natural systems or impede ecological processes. Sea walls and levees are two specific examples of "gray infrastructure" that communities may identify as needs for protection from sea level rise and river flooding, yet these structures can reduce habitat values, and put species and natural processes at risk. Actions that are identified during this step are likely to focus on improving communication with stakeholders that have a need for services that natural systems could provide, and helping foster partnerships that encourage investments in nature-based rather than gray infrastructure. This is an example of where fostering of long-term relationships across different sectors is especially needed so that people with appropriate expertise can be involved early and often. Gray infrastructure-type responses to the risks of climate change have long planning periods and are very costly to retrofit (Kousky 2010, Downing et al. 2013). This step should also serve to help remind managers to invest time in summarizing their investments in activities such as restoring wetlands that help prevent floods, or in increasing the size of culverts that support road-stream crossings to prepare for flashier flows. When extreme events take place, these data coupled with comparative analyses from economists or hazard management specialists on comparative costs across areas with fewer wetlands or smaller pipes can be some of our strongest tools for inspiring greater investments in actions that benefit both people and nature.

STEP 4. DETERMINE WHICH CLIMATE IMPACTS ARE CRITICAL, AND CAN BE ADDRESSED In the process described by Poiani et al. (2011), the next step involves ranking the risks posed by climate change (as stated in step 2), and integrating these lists with existing management priorities. The goal here is to focus in on a small number of risks that can feasibly be addressed through some changes in management, so that these can become the focus of adaptation strategies. This prioritization step can be addressed in many different ways—it may be useful to focus in on one of the most tractable risks first, simply to help provide momentum to the process of investing in adaptation efforts. Over the long term, it will likely be important to develop clear criteria for addressing climate risks, as there is no doubt that the resources needed to address even a limited number of vulnerabilities will exceed the funds available. This is the most obvious step where science must be integrated with societal values, which can be easier if we have some structure to help us frame comparisons, and communicate options to the public. To this end, Schneider et al. (2007, p.785–786) outlined seven criteria for defining "key vulnerabilities" as part of the Fourth Intergovernmental Panel on Climate Change (IPCC) Assessment. The concept of key vulnerabilities can be applied to any type of system that is susceptible to the impacts of climate change (e.g., ecological, human infrastructure, public health). These factors provide a thought-provoking way to filter through long lists of impacts to produced prioritized adaptation actions, and related discussions are likely to range far beyond science and management.

- Magnitude of impact (area, number of species / systems, costs to restore or promote adaptation);

- Timing (rate of change, near or far-off in time);
- Persistence and reversibility (i.e., extinctions vs. population declines; climate change as a trigger for change in land use that would limit future ecological values);
- Likelihood of impacts and vulnerabilities, and confidence in those estimates (probability that the impact will occur, as assessed through statistical tools and / or expert opinion);
- Potential for adaptation (to what extent do species have the genetic variability, dispersal abilities, etc., needed to adapt to changes, and can we implement needed strategies given current regulatory constraints?);
- Distribution of impacts and vulnerabilities (IPCC focuses on equity issues; this could be seen as pattern of impacts relative to the distribution of a population, or could provide a mechanism for considering variation across different stakeholder groups in the impact of climate-related changes in ecosystem services to people);
- Importance of the system at risk (e.g., cultural value, economic value, ecological value).

STEP 5. EVALUATE IF POTENTIAL CLIMATE CHANGE IMPACTS ARE LIKELY TO CHANGE FUNDAMENTALLY THE PROJECT, OR PRECLUDE PROJECT SUCCESS This step serves as a reminder that static goals may no longer make sense with respect to managing systems in a nonstationary climate, and some aspects of change may be in direct conflict with sustaining particular species or systems at a site. As in the step above, this step requires integration of science with values and has the potential to lead to discussions that range far beyond the science and on-the-ground management practices. As we delve into our goals, we are likely to uncover that not all share the same perspective on principles that underlie our work, such as the value of "naturalness," the purpose of parks, national forests, or other types of public-trust resources, and the appropriateness of various levels of intervention (Hobbs et al. 2010[AQ2]). As these ideas suggest, managers should expect the steps in any approach to adaptation to be iterative and nonlinear—sometimes you need to step backward to move forward. With respect to thinking about how goals can be reframed, three terms are commonly used to frame approaches to adaptation: Resistance (act to slow the rate of change and protect valued resources); resilience (act to promote ability to bounce back from disturbance, and stay within some range of conditions); and response / transformation to a different state or system type (e.g., Millar et al. 2007, Heller and Zavaleta 2009, West et al. 2009). In their work on Mediterranean forests of California, Stephens et al. (2010) present a fourth category, realignment, that addresses using management to reset the trajectory of systems to account for reduced ability to adapt to new conditions due to factors such as past management history. Depending on the missions of particular management organizations, choices of how to proceed may be constrained due to conflicts with core principles, or partnerships may be strained due to differences in perspective that are brought to the forefront by climate change. In other cases, a key strategy that emerges from these conversations may be to revisit project goals, or even an organization's mission.

AQ2: Reference "Hobbs et al. 2011" has been changed to "Hobbs et al. 2010" as per information provided in Literature cited. Please check.

STEP 6. DEVELOP ADAPTATION STRATEGIES AND EVALUATE THEIR FEASIBILITY AND COST Adaptation strategies can range from minor "tweaks" in practices (e.g., changing the timing of some actions, like mowing or prescribed burns) to more costly changes to entirely new practices. Again, in this short review we hope to provide context for how the impact information, and management goals and constraints, connects with adaptation planning. However, many resources to help with the framing of adaptation strategies are available, ranging from general ideas (Heller and Zavaleta 2009, Lawler 2009, West et al. 2009, Hansen and Hoffman 2011, Stein et al. 2014) to system-specific examples and case studies for California (e.g., Millar et al. 2007, Stephens et al. 2010, Downing et al. 2013). This growing literature on climate change adaptation has identified the need to take a very proactive approach, especially in the context of protecting species and ecological systems that are already at risk (West et al. 2009, Lawler et al. 2010, Poiani et al. 2011[AQ3]). Being proactive entails identifying climate change as a significant threat, indicating consequences it would likely have, and identifying specifically how to address those threats through a set of actions designed to reduce probable future risks.

AQ3: Reference "Poiani et al. 2010" has been changed to "Poiani et al. 2011" as per information provided in Literature cited. Please check.

The step of identifying adaptation strategies reminds us to assess the costs and benefits of changes in management, a process that should link back to the hypotheses of change that we defined above. A key checkpoint to consider is, do the actions you have identified as adaptation directly address a priority impact? The most successful adaptation actions will clearly show this logical flow, and through our ability to explain the rationale behind our choices will help build public support for actions that may be more costly than "business as usual." As different forms of guidance have emerged, one can sense tension with respect to what kind of management actions "count" as adaptation. For example, increasing connectivity is often one of the first concepts to emerge in climate adaptation conversations, and it may be tempting to then say that any effort to promote connectivity also promotes adaptation. The idea of acting "with intention" (e.g., Stein et al. 2014) provides an important cross-check on our list of strategies. If, rather than linking each adaptation action to a specific reduced risk, we call any action that possibly increases connectivity or reduces the impact of some stressor (like invasive species) a climate adaptation strategy, we will be less effective, and weaken support and understanding for our efforts. These activities are still vital, and often do promote adaptation, but we should be prepared to describe how, and for what species or system, future viability is likely to be enhanced. Clearly, they may also be vital for other reasons beyond climate change adaptation, and being clear in our logic can help us make the case that they are still important, even if there are few climate-related benefits.

If the task of overhauling management for an area to address climate change seems daunting at first, a useful first step may be to evaluate and modify current actions that are clearly counterproductive or are at high risk of having benefits negated as a result of climate change. For example, it may be straightforward to compare the longevity of some investments, as in the case of restoration of coastal wetlands that vary in terms of exposure and resilience to increasing sea levels (Stralberg et al. 2011). Similarly, another fruitful first strategy may be to update ongoing monitoring work to ensure that data collection efforts are useful for evaluating changes attributable to climate change. In some cases, this is as simple as including local climatic measures in the monitoring scheme or extending the temporal extent of monitoring such that changes in timing of events can be captured. This form of coordination can provide the data needed to develop additional strategies in the future. Similarly, an early step to help identify site-specific changes that could inform on-the-ground strategies could involve a systematic review of information collected in the past, as described by Tingley (Chapter 13).

STEP 7. DEVELOP MEASURES OF SUCCESS, IMPLEMENT, ADAPT, AND LEARN To restore, maintain, and protect biodiversity as the climate changes, it is more important than ever to have clear ways of defining and measuring the success of our actions. Although full coverage of monitoring and data sharing among resource managers is beyond the scope of this chapter, these activities represent an essential follow-up to "asking the climate question" of our management goals and decisions. Strengthening our inference and defining measure of success that help us communicate with a wide range of stakeholders are urgent needs. As such, they represent challenging but likely fruitful areas for collaborations among scientists, managers, and policy-makers.

FROM INCREASED COLLABORATION TO ACTION

To build upon the chapters here, which are part of a rapidly growing body of information on species and system responses, we need to step up collaborative, multi-stakeholder efforts that support implementation of key actions, and changes in policy. Specifically, to build the momentum that moves science-based ideas into actions on the ground, we need to involve a broad range of stakeholders, and be clear on how various adaptation strategies may benefit, or harm, the things that each group values. The decisions that need to be made now and in the future require that as scientists we understand that science needs to be framed in such a way that a wide range of stakeholders can evaluate results and use these to inform value judgments on how scarce resources are used. We also need to invest in communication and become more comfortable with stating our assumptions and values, as these are critical building blocks for improving understanding. To do the best we can in supporting functioning natural systems, we will need to prepare for surprises in how species and systems respond, and think about rules for "triage," as not all species will be viable (at a defensible cost) in future climates (Root and Schneider 2006, Lawler 2009). At the risk of oversimplification, progress on the collaboration side can be measured by answering three questions: (1) Are we talking to each other? (2) Is there shared understanding on the key issues and options? (3) Can we identify shared goals, and ways to achieve them? Collaborations can break down in any of these areas, and tools for promoting collaboration seem especially needed when trying to bring people together around issues with this level of complexity and uncertainty.

Taken together, all of these components of responding to climate change suggest that we have entered a new era with respect to the skill sets that will be most useful to scientists that enter ecological fields, either as academic or agency researchers, practitioners within nongovernmental organizations, or as resource managers. While no one person, or even organization, is likely to include the full range of expertise needed to meet this challenge, we can benefit both nature and ourselves if we broaden our perspectives and strengthen our connections.

LITERATURE CITED

AFWA. 2009. *Voluntary Guidance for States to Incorporate Climate Change into State Wildlife Action Plans and Other Management Plans.* A Collaboration of the AFWA Climate Change and Teaming with Wildlife Committees, Association of Fish and Wildlife Agencies. Washington, DC. http://www.fishwildlife.org/files/AFWA-Voluntary-Guidance-Incorporating-Climate-Change_SWAP.pdf.

Barsugli, J. J., G. Guentchev, R. M. Horton, A. Wood, L. O. Mearns, X.-Z. Liang, J. A. Winkler, K. Dixon, K. Hayhoe, R. B. Rood et al. 2013. The practitioner's dilemma: How to assess the credibility of downscaled climate projections. *Eos, Transactions American Geophysical Union* 94:424–425.

Bierbaum, R., J. B. Smith, A. Lee, M. Blair, L. Carter, F. S. Chapin III, P. Fleming, S. Ruffo, M. Stults, S. McNeeley et al. 2013. A comprehensive review of climate adaptation in the United States: More than before, but less than needed. *Mitigation and Adaptation Strategies for Global Change* 18:361–406.

Cross, M. S., E. S. Zavaleta, D. Bachelet, M. L. Brooks, C. A. F. Enquist, E. Fleishman, L. Graumlich, C. R. Groves, L. Hannah, L. Hansen et al. 2012. The adaptation for conservation targets (ACT) framework: A tool for incorporating climate change into natural resource management. *Environmental Management* 50:341–351.

Downing, J., L. Blumberg, and E. Hallstein. 2013. *Reducing Climate Risks with Natural Infrastructure.* The Nature Conservancy, San Francisco, CA. 29 pp. http://www.nature.org/ourinitiatives/regions/northamerica/unitedstates/california/ca-green-vs-gray-report-2.pdf.

Gardali, T., N. E. Seavy, R. T. DiGaudio, and L. A. Comrack. 2012. A climate change vulnerability assessment of California's at-risk birds. *PLOS ONE* 7:e29507.

Gartner, T., J. Mulligan, R. Schmidt, and J. Gunn. 2013. *Natural Infrastructure: Investing in Forested Landscapes for Source Water Protection in the*

United States. World Resources Institute, Washington, DC. http://www.wri.org/publication/natural-infrastructure.

Glick, P., B. A. Stein, and N. A. Edelson (eds). 2011. *Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment*. National Wildlife Federation, Washington, DC.

Gregory, R., L. Failing, D. Ohlson, and T. L. McDaniels. 2006. Some pitfalls of an overemphasis on science in environmental risk management decisions. *Journal of Risk Research* 9:717–735.

Hagerman, S. M. and T. Satterfield. 2013. Entangled judgments: Expert preferences for adapting biodiversity conservation to climate change. *Journal of Environmental Management* 129:555–563.

Hagerman, S. M. and T. Satterfield. 2014. Agreed but not preferred: Expert views on taboo options for biodiversity conservation, given climate change. *Ecological Applications* 24:548–559.

Hansen, L. J. and J. R. Hoffman. 2011. *Climate Savvy: Adapting Conservation and Resource Management to a Changing World*. Island Press, Washington, DC. 245 pp.

Heller, N. E. and E. S. Zavaleta. 2009. Biodiversity management in the face of climate change: A review of 22 years of recommendations. *Biological Conservation* 142:14–32.

Hobbs, R. J., D. N. Cole, L. Yung, E. S. Zavaleta, G. H. Aplet, F. S. Chapin, P. B. Landres, D. J. Parsons, N. L. Stephenson, P. S. White et al. 2010. Guiding concepts for park and wilderness stewardship in an era of global environmental change. *Frontiers in Ecology and the Environment* 8:483–490.

Hoffman, J., E. Rowland, C. H. Hoffman, J. West, S. Herrod-Julius, and M. Hayes. 2014. Managing under uncertainty, Chapter 12. In B. A. Stein, P. Glick, N. Edelson, and A. Staudt (eds), *Climate-Smart Conservation: Putting Adaptation Principles into Practice*. National Wildlife Federation, Washington, DC.

IPCC. 2007. In S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, and H. L. Miller (eds), *Climate Change 2007: The Physical Science Basis. Contribution of Working Group 1 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* Cambridge University Press, Cambridge, UK and New York, NY, USA. 996 pp.[AQ4].

AQ4: Please provide the chapter title, and cite the reference in the text.

Joyce, L. A., G. M. Blate, S. G. McNulty, C. I. Millar, S. Moser, R. P. Neilson, and D. L. Peterson. 2009. Managing for multiple resources under climate change: National forests. *Environmental Management* 44:1022–1032.

Kates, R. W., W. R. Travis, and T. J. Wilbanks. 2012. Transformational adaptation when incremental adaptations to climate change are insufficient. *Proceedings of the National Academy of Sciences of the United States of America* 109:7156–7161.

Keeney, R. L. 2004. Making better decision makers. *Decision Analysis* 1:193–204.

Kelly, A. E. and M. L. Goulden. 2008. Rapid shifts in plant distribution with recent climate change. *Proceedings of the National Academy of Sciences of the United States of America* 105:11823–11826.

Klausmeyer, K. R., M. R. Shaw, J. B. MacKenzie, and D. R. Cameron. 2011. Landscape-scale indicators of biodiversity's vulnerability to climate change. *Ecosphere* 2:art88.

Kousky, C. 2010. Using natural capital to reduce disaster risk. *Journal of Natural Resources Policy Research* 2:343–356.

Kujala, H., M. A. Burgman, and A. Moilanen. 2013. Treatment of uncertainty in conservation under climate change. *Conservation Letters* 6:73–85.

Lawler, J. J. 2009. Climate change adaptation strategies for resource management and conservation planning. *Annals of the New York Academy of Sciences* 1162:79–98. Year in Ecology and Conservation Biology 2009.

Lawler, J. J., T. H. Tear, C. Pyke, M. R. Shaw, P. Gonzalez, P. Kareiva, L. Hansen, L. Hannah, K. Klausmeyer, A. Aldous et al. 2010. Resource management in a changing and uncertain c limate. *Frontiers in Ecology and the Environment* 8:35–43.

Loarie, S. R., B. E. Carter, K. Hayhoe, S. McMahon, R. Moe, C. A. Knight, and D. D. Ackerly. 2008. Climate change and the future of California's endemic flora. *PLOS ONE* 3:e2502.

Martin, J., M. C. Runge, J. D. Nichols, B. C. Lubow, and W. L. Kendall. 2009. Structured decision making as a conceptual framework to identify thresholds for conservation and management. *Ecological Applications* 19:1079–1090.

Mastrandrea, M., N. Heller, T. Root, and S. Schneider. 2010. Bridging the gap: Linking climate-impacts research with adaptation planning and management. *Climatic Change* 100:87–101.

McLaughlin, J. F., J. J. Hellmann, C. L. Boggs, and P. R. Ehrlich. 2002. Climate change hastens population extinctions. *Proceedings of the National Academy of Sciences of the United States of America* 99:6070–6074.

Millar, C. I., N. L. Stephenson, and S. L. Stephens. 2007. Climate change and forests of the future:

Managing in the face of uncertainty. *Ecological Applications* 17:2145–2151.

Milly, P.C.D., J. Betancourt, M. Falkenmark, R.M. Hirsch, Z.W. Kundzewicz, D.P. Lettenmaier, and R.J. Stouffer. 2008. Stationarity is dead: Whither water management? *Science* 319:573–574.

Moser, S.C. and J.A. Ekstrom. 2010. A framework to diagnose barriers to climate change adaptation. *Proceedings of the National Academy of Sciences of the United States of America* 107:22026–22031.

National Research Council. 2009. *Informing Decisions in a Changing Climate. Panel on Strategies and Methods for Climate-Related Decision Support, Committee on the Human Dimensions of Global Change. Division of Behavioral and Social Sciences and Education.* The National Academies Press, Washington, DC. 188 pp.

Park, S.E., N.A. Marshall, E. Jakku, A.M. Dowd, S.M. Howden, E. Mendham, and A. Fleming. 2012. Informing adaptation responses to climate change through theories of transformation. *Global Environmental Change-Human and Policy Dimensions* 22:115–126.

Petersen, B.C., K.R. Hall, K.J. Kahl, and P.J. Doran. 2013. In their own words: Perceptions of climate change adaptation from the Great Lakes region's resource management community. *Environmental Practice* 15:377–392.

Poiani, K.A., R.L. Goldman, J. Hobson, J.M. Hoekstra, and K.S. Nelson. 2011. Redesigning biodiversity conservation projects for climate change: Examples from the field. *Biodiversity Conservation* 20:185–201.

Root, T.L. and S.H. Schneider. 2006. Conservation and climate change: The challenges ahead. *Conservation Biology* 20:706–708.

Rowland, E.L., J.E. Davison, and L.J. Graumlich. 2011. Approaches to evaluating climate change impacts on species: A guide to initiating the adaptation planning process. *Environmental Management* 47:322–337.

Schneider, S.H., S. Semenov, A. Patwardhan, I. Burton, C.H.D. Magadza, M. Oppenheimer, A.B. Pittock, A. Rahman, J.B. Smith, A. Suarez et al. 2007. Assessing key vulnerabilities and the risk from climate change. In M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson (eds), *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the IPCC*. Cambridge University Press, Cambridge, UK. 779–810.

Solomon, S., G.K. Plattner, R. Knutti, and P. Friedlingstein. 2009. Irreversible climate change due to carbon dioxide emissions. *Proceedings of the National Academy of Sciences of the United States of America* 106:1704–1709.

Stein, B.A., P. Glick, N. Edelson, and A. Staudt (eds). 2014. *Climate-Smart Conservation: Putting Adaptation Principles into Practice*. National Wildlife Federation, Washington, DC.

Stephens, S.L., C.I. Millar, and B.M. Collins. 2010. Operational approaches to managing forests of the future in Mediterranean regions within a context of changing climates. *Environmental Research Letters* 5(2):024003. doi: 10.1088/1748-9326/1085/1082/024003.

Stralberg, D., M. Brennan, J.C. Callaway, J.K. Wood, L.M. Schile, D. Jongsomjit, M. Kelly, V.T. Parker, and S. Crooks. 2011. Evaluating tidal marsh sustainability in the face of sea-level rise: A hybrid modeling approach applied to San Francisco Bay. *PLOS ONE* 6:e27388.

Thomas, C.D., J.K. Hill, B.J. Anderson, S. Bailey, C.M. Beale, R.B. Bradbury, C.R. Bulman, H.Q.P. Crick, F. Eigenbrod, H.M. Griffiths et al. 2011. A framework for assessing threats and benefits to species responding to climate change. *Methods in Ecology and Evolution* 2:125–142.

West, J.M., S.H. Julius, P. Kareiva, C. Enquist, J.J. Lawler, B. Petersen, A.E. Johnson, and M.R. Shaw. 2009. US natural resources and climate change: Concepts and approaches for management adaptation. *Environmental Management* 44:1001–1021.

West, J.M., S.H. Julius, and C.P. Weaver. 2012. Assessing confidence in management adaptation approaches for climate-sensitive ecosystems. *Environmental Research Letters* 7(1):014016. doi:10.1088/1748-9326/7/1/014016.

Wilsey, C.B., J.J. Lawler, E.P. Maurer, D. McKenzie, P.A. Townsend, R. Gwozdz, J.A. Freund, K. Hagmann, and K.M. Hutten. 2013. Tools for assessing climate impacts on fish and wildlife. *Journal of Fish and Wildlife Management* 4:220–241.