University of Nebraska - Lincoln
DigitalCommons@University of Nebraska - Lincoln

USDA Forest Service / UNL Faculty Publications

U.S. Department of Agriculture: Forest Service -- National Agroforestry Center

2014

# Chapter 8: Adapting to Climate Change

Constance I. Miller
*Pacific Southwest Research Station, U.S. Forest Service, Albany, CA, USA*, cmillar@fs.fed.us

Christopher W. Swanson
*Northern Research Station, U.S. Forest Service, Houghton, MI, USA*, cswanston@fs.fed.us

David L. Peterson
*Pacific Northwest Research Station, U.S. Forest Service, Seattle, WA, USA*, peterson@fs.fed.us

Follow this and additional works at: http://digitalcommons.unl.edu/usdafsfacpub

Miller, Constance I.; Swanson, Christopher W.; and Peterson, David L., "Chapter 8: Adapting to Climate Change" (2014). *USDA Forest Service / UNL Faculty Publications*. 271.
http://digitalcommons.unl.edu/usdafsfacpub/271

This Article is brought to you for free and open access by the U.S. Department of Agriculture: Forest Service -- National Agroforestry Center at DigitalCommons@University of Nebraska - Lincoln. It has been accepted for inclusion in USDA Forest Service / UNL Faculty Publications by an authorized administrator of DigitalCommons@University of Nebraska - Lincoln.

# Chapter 8
# Adapting to Climate Change

**Constance I. Millar, Christopher W. Swanston, and David L. Peterson**

## 8.1 Principles for Forest Climate Adaptation

Forest ecosystems respond to natural climatic variability and human-caused climate change in ways that are adverse as well as beneficial to the biophysical environment and to society. Adaptation can be defined as responses or adjustments made—passive, reactive, or anticipatory—to climatic variability and change (Carter et al. 1994). Many adjustments occur whether humans intervene or not; for example, plants and animals shift to favorable habitats, and gene frequencies may change to favor traits that enable persistence in a warmer climate.

Here we assess (general) strategies and (specific) tactics that resource managers can use to reduce forest vulnerability and increase adaptation to changing climate (Peterson et al. 2011). Plans and activities range from short-term, stop-gap measures, such as removing conifers that are progressively invading mountain meadows, to long-term, proactive commitments, such as vegetation management to reduce the likelihood of severe wildfire or of beetle-mediated forest mortality.

C.I. Millar
Pacific Southwest Research Station, U.S. Forest Service, Albany, CA, USA
e-mail: cmillar@fs.fed.us

C.W. Swanston
Northern Research Station, U.S. Forest Service, Houghton, MI, USA
e-mail: cswanston@fs.fed.us

D.L. Peterson (✉)
Pacific Northwest Research Station, U.S. Forest Service, Seattle, WA, USA
e-mail: peterson@fs.fed.us

D.L. Peterson et al. (eds.), *Climate Change and United States Forests*, Advances in Global Change Research 57, DOI 10.1007/978-94-007-7515-2_8,
© Springer Science+Business Media Dordrecht (outside the USA) 2014

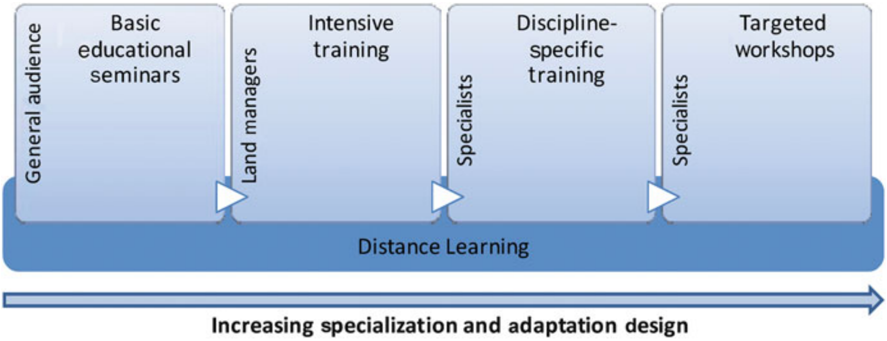


**Fig. 8.1** Conceptual diagram of educational and training efforts leading to increased complexity of adaptation planning and activities. These elements are integrated but need not be taken consecutively. Distance learning can be incorporated into all activities (From Peterson et al. 2011)

### *8.1.1 Adaptation Planning and Implementation*

Adaptation strategies, plans, and management actions are generally tied to broad goals of ecosystem sustainability. Restoration, maintenance, and promotion of natural ecological processes and ecosystem services define the mission of most public land-management agencies and many private lands where production forestry is not dominant. Successful implementation of climate adaptation plans occurs when projects are developed and deployed for specific places with concrete treatments and prescriptions, explicit objectives, and for definitive time periods. Successful implementation also implies that monitoring and adaptive management (in a general sense) will continue for the duration of the adaptation effort.

### *8.1.2 Education and Training*

Training for land management professionals in the fundamental concepts of climatology and physical and ecological sciences related to climate change is essential. Such knowledge will increase the institutional capacity to understand potential effects of climate change and associated uncertainty, and to construct appropriate strategies and actions. A multi-level approach facilitates climate change education and dialogue. Recently developed education programs (Peterson et al. 2011; Swanston and Janowiak 2012) have incorporated several elements including basic education, intensive training, and discipline-specific and targeted workshops (Fig. 8.1). Short (1- to 2-day) basic educational seminars convey fundamental principles of climate change and the effects of climate change on ecosystems and generate discussion of how different resources under management consideration can adapt to projected changes. Intensive training includes week-long courses providing detailed information on fundamental climate processes and interactions, as well as mechanisms of forest response to climate stressors. Participants have the opportunity to evaluate issues or resources by using available (e.g., online) tools. Discipline-specific trainings allow focused presentation and discussion of climate change implications for specific resource issues (e.g., silviculture, wildlife).

### *8.1.3 Science-Management Partnerships*

Partnerships between scientists and resource managers are a critical foundation for understanding climate science and developing adaptation strategies. These collaborations can develop in different forms. For example, science information might reside within an agency, but in different program areas than those traditionally involved with forest management. University extension specialists have a long history of spanning boundaries between science and applications (e.g., providing genetic expertise in developing seed-transfer rules), and can be included in partnerships. Research scientists with universities and agencies increasingly participate in resource management collaborations. Interactive dialogue is a key element in these collaborations, with managers and scientists reciprocally learning from and informing each other about relevance. A short-term commitment, typically two years or more, will be needed to develop adaptation strategies and tactics, and a longer commitment is advisable to ensure that new science is considered and adaptation effectiveness is evaluated over time.

### *8.1.4 Risk and Uncertainty*

Given the environmental complexities of forest ecosystems and the diverse and often conflicting societal issues associated with forests, resource managers and decision makers are accustomed to the challenges of risk and uncertainty. Climate change adds new dimensions of uncertainty, increasing the complexity of risk analyses. Trends in climate and ecosystem response can be bounded with probabilistic envelopes that describe what is likely to occur in the future, but unexpected conditions and surprises are likely, especially at local scales. Effective forest adaptation strategies need to (1) be aware of risks, (2) assess vulnerabilities, (3) develop adaptation responses that are realistic yet minimize uncertainties, and (4) incorporate new knowledge and over time to modify decisions as appropriate (essentially the adaptive management process) (Moser and Luers 2008). Adaptation responses to risk include (1) no action—continue conventional practices, (2) contingency planning—develop a response strategy (e.g., to anticipated major disturbance), and (3) anticipatory and proactive strategies—curtail or diminish potential impacts (e.g., of a major disturbance) while optimizing attainment of goals (Joyce et al. 2008).

### 8.1.5 Toolkit Approach

Novelty and surprise in climate change effects, combined with multiple management objectives at different spatial and temporal scales, mean that no single approach will fit all situations. A toolkit approach to adaptation strategies recognizes that the best strategy will require selecting appropriate methods for the specific situation. Tools include resource management practices, educational and reference modules, decision support aids, and qualitative and quantitative models that address adaptation of natural and cultural resources to climate change (Peterson et al. 2011). Tools include existing management practices, perhaps used in new ways, as well as novel approaches developed to meet climate challenges.

### 8.1.6 No-Regrets Decision Making

"No-regrets" decision making refers to actions that result in a variety of benefits under multiple scenarios and have little or no risk of undesirable outcomes. This can include (1) implementing fuel treatments in dry forests to reduce fire hazard and facilitate ecological restoration, while creating resilience to increased fire occurrence in a warmer climate, and (2) installing new, larger culverts in locations where peak flows during flooding are expected to be higher in a warmer climate, thus protecting roads and reducing maintenance costs. These types of actions benefit resources and values regardless of climate change effects and can be implemented in the near term (Swanston and Janowiak 2012).

### 8.1.7 Flexibility and Adaptive Learning

Because future climates and ecosystem responses are uncertain, our experience in developing forest adaptation strategies is limited, flexibility, experimentation, and adaptive learning should be incorporated in adaptation strategies. Although a formal adaptive management program should normally be developed in conjunction with implemented projects, other approaches to monitoring that facilitate modified management practices are also appropriate.

### 8.1.8 Mixed-Models Approach

Climate- and ecosystem-response models are proliferating, and downscaled climate change scenarios may seem useful for conducting vulnerability analyses and developing adaptation responses at local to regional scales. However, given uncertainty in both climate models and response models, output from projections should be used cautiously. Models are often useful for examining forest response to recent historical events and for attributing causality (e.g., identifying climatic factors that influence large wildfires or insect outbreaks); however, they are often less useful for forecasting at small spatial scales or over long time periods. Output from models is useful as background information for envisioning a range of potential futures rather than to project a single outcome. The use of different types of models—with different assumptions, process interactions, and input data—to address the same issue is recommended. Both quantitative (algorithm based) and qualitative (e.g., flow charts, indices, and verbal tools) models should are useful, and projected futures can be compared. In recent years, it has been suggested that, if a model (or several models) hindcasts observed historical conditions well, it will also accurately predict future conditions. This is not necessarily true, because models can produce a correct historical reconstruction for the wrong reasons (Crook and Forster 2011), which means that forecasts could also be wrong. Given the limitations of models, resource professionals should not hesitate to use their experience and judgment to evaluate model projections of future climate and ecosystem responses. Daniels et al. (2012) provide a straightforward guide for effective use of models.

### *8.1.9 Integration with Other Priorities and Forest Management Objectives*

Adaptation strategies need to be integrated with mitigation activities (actions to reduce human influence on the climate system) (Metz et al. 2001). Adaptation and mitigation goals are preferably considered concurrently, although in some situations strategies may conflict, and compromise choices may be required. Climate change is only one of many challenges confronting forest management, and other priorities must be evaluated at different temporal scales. For example, managing under the Endangered Species Act of 1973 (ESA) can invoke actions that are legally required in the short term but are illogical, given long-term projections of the effects of climate change. For forest lands where ecological sustainability is the central goal, ecosystem-based management as practiced in land management since the late 1980s (e.g., Lackey 1995; Kohm and Franklin 1997) provides a foundation for addressing most climate change effects. Ecosystem-based management acknowledges that natural systems change continuously and that such dynamics bring high levels of uncertainty. Ecosystem-based management concepts are therefore an appropriate foundation for forest adaptation.

## 8.2 The Context for Adaptation

Adaptation strategies will differ for different forest ecosystems as a function of the diversity of biophysical characteristics and biosocial issues associated with each forest. Climate change affects forest ecosystems at many temporal and spatial

**Table 8.1** Factors that affect the relevance of information for assessing vulnerability to climate change of large, intermediate, and small spatial scales

| | Relevance by spatial scale | | |
|---|---|---|---|
| Factors | Large[a] | Intermediate[b] | Small[c] |
| Availability of information on climate and climate change effects | High for future climate and general effects on vegetation and water | Moderate for river systems, vegetation, and animals | High for resource data, low for climate change |
| Accuracy of predictions of climate change effects | High | Moderate to high | High for temperature and water, low to moderate for other resources |
| Usefulness for specific projects | Generally not relevant | Relevant for forest density management, fuel treatment, wildlife, and fisheries | Can be useful if confident that information can be downscaled accurately |
| Usefulness for planning | High if collaboration across management units is effective | High for a wide range of applications | Low to moderate |

Modified from Peterson et al. (2011)
[a]More than 10 000 $km^2$ (e.g., basin, multiple national forests)
[b]100–10 000 $km^2$ (e.g., subbasin, national forest, ranger district)
[c]Less than 100 $km^2$ (e.g., watershed)

scales, for example, from its influence on timing of bud burst to the evolution of leaf morphology, and from trophic interactions on a rotting log to shifts in biome distribution across continents. The longevity of forest trees, their influence on the physical landscape (e.g., soil development, watershed quality), and role as habitat add complexity to scale issues. Analysis at the correct spatial scales is especially important for assessing trends of climate change and ecological response, given that averages and trends on broad scales (e.g., continental) can mask variability at fine scales (e.g., watershed) (Wiens and Bachelet 2010).

An adaptation framework based on appropriate temporal and spatial scales (e.g., Peterson and Parker 1998) ensures that plans and activities address climate effects and responses effectively. Because scales are nested, the best strategies focus on the scale of the relevant project and include evaluation of conditions and effects at scales broader than the project level, as well as analysis of effects at finer scales (Tables 8.1, 8.2). Broad-scale analysis establishes context, including recognition of processes and effects observed only at large scales (e.g., species decline, cumulative watershed effects) and possible adverse consequences that could be alleviated by early action.

Most public forest lands are managed for long-term ecological sustainability, although emphasis differs by designation for protection level (parks, wilderness, and reserves) and ecosystem services (national and state forests, Bureau of Land Management [BLM] forest and woodlands, and tribal forest lands). Conservation on

**Table 8.2** Factors that affect the relevance of information for assessing vulnerability to climate change of large, intermediate, and small time scales

| | Relevance by time scale | | |
|---|---|---|---|
| Factor | Large[a] | Intermediate[b] | Small[c] |
| Availability of information on climate and climate change effects | High for climate, moderate for effects | High for climate and effects | Not relevant for climate change and effects predictions |
| Accuracy of predictions of climate change effects | High for climate and water, low to moderate for other resources | High for climate and water, moderate for other resources | Low |
| Usefulness for specific projects | High for temperature and water, low to moderate for other resources | High for water, moderate for other resources | Low owing to inaccuracy of information at this scale |
| Usefulness for planning | High | High for water, moderate for other resources | Low |

Modified from Peterson et al. (2011)
[a]More than 50 years
[b]5 to 50 years
[c]Less than 5 years

U.S. public lands is subject to legal and regulatory direction, such as the National Environmental Policy Act [NEPA] of 1969, Clean Air Act of 1970, Clean Water Act of 1977, and ESA. Goals and time horizons of adaptation strategies for public lands differ from those for private lands. Adaptation on industrial forest land focuses on sustaining productive output over a given period of economic analysis (Sedjo 2010), whereas adaptation on nonindustrial private forest lands differs according to the goals and capacities of individual landowners.

## 8.3 The Adaptation Process

### *8.3.1 Overview of Forest Adaptation Strategies*

The literature on forest adaptation strategies (Baron et al. 2008; Joyce et al. 2008; Peterson et al. 2011; Swanston and Janowiak 2012) (Table 8.3) includes broad conceptual frameworks, approaches to specific types of analyses (e.g., vulnerability assessments, scenario planning, adaptive management), and tools and guidance for site-specific and issue-specific problems. Adaptation at the highest conceptual level in forest ecosystems focuses on resistance, resilience, response, and realignment strategies (Millar et al. 2007) (Box 8.1). These general principles help to identify the scope and scale of appropriate options at the broadest levels (Spittlehouse 2005),

**Table 8.3** Climate adaptation guides relevant to the forest sector

| Category | Emphasis | Reference |
|---|---|---|
| Adaptation framework | General options for wildlands | Millar et al. (2007) |
| | Options for protected lands | Baron et al. (2008, 2009) |
| | Adaptation guidebooks | Snover et al. (2007), Peterson et al. (2011), Swanston and Janowiak (2012) |
| Vulnerability analysis | Climate change scenarios | Cayan et al. (2008) |
| | Scenario exercises | Weeks et al. (2011) |
| | Forest ecosystems | Aubry et al. (2011), Littell et al. (2010) |
| | Watershed analysis | Furniss et al. (2010) |
| Genetic management | Seed transfer guidelines | McKenney et al. (2009) |
| | Risk assessment | Potter and Crane (2010) |
| Assisted migration | Framework for translocation | McLachlan et al. (2007), Ricciardi and Simberloff (2009) |
| Decision making | Silvicultural practices | Janowiak et al. (2011b) |
| | Climate adaptation workbook | Janowiak et al. (2011a) |
| Priority setting | Climate project screening tool | Morelli et al. (2011b) |

**Box 8.1: A General Framework for Adaptation Options Suitable for Forested Ecosystems**

Options range from short-term, conservative strategic approaches to strategies for long-term, proactive plans (from Millar et al. 2007):

**Promote Resistance**

Actions that enhance the ability of species, ecosystems, or environments to resist forces of climate change and that maintain values and ecosystem services in their present or desired states and conditions

**Increase Resilience**

Actions that enhance the capacity of ecosystems to withstand or absorb increasing impact without irreversible changes in important processes and functionality

**Enable Ecosystems to Respond**

Actions that assist climatically driven transitions to future states by mitigating and minimizing undesired and disruptive outcomes

**Realign Highly Altered Ecosystems**

Actions that use restoration techniques to enable ecosystem processes and functions (including conditions that may or may not have existed in the past) to persist through altered climates and in alignment with changing conditions but they do not provide guidance for developing site-specific plans. In some cases, it may be necessary to consider overarching issues that affect the scientific context for adaptation, such as historical variability, ecological change over time, and use of historic targets in management and restoration (Harris et al. 2006; Milly et al. 2008; Jackson 2012).

Special concerns for adaptation in parks and protected areas (Baron et al. 2008, 2009; Stephenson and Millar 2012) emphasize that future ecosystems will differ from the past, and that fundamental changes in species and their environments will be inevitable. Effective adaptation will need to identify resources and processes at risk, define thresholds and reference conditions, and establish monitoring and assessment programs (adaptive management). Preparing for and adapting to climate change is as much a cultural and intellectual challenge as an ecological issue. Diverse regulations and values dictate desired future ecosystem conditions, which in turn drive decisions about goals, strategies, and actions (Baron et al. 2009).

The reality of change and novelty in future forest ecosystems underscores the importance of vulnerability assessments in developing adaptation strategies (Littell and Peterson 2005; Spittlehouse 2005; Johnstone and Williamson 2007; Nitschke and Innes 2008; Lindner et al. 2010; Littell et al. 2010; Aubry et al. 2011). Vulnerability assessments can differ in terms of subject matter, geographic focus, level of detail, and quantitative rigor. Regional-scale assessments can be cautiously downscaled to smaller management units, recognizing there will be tradeoffs in accuracy. Watersheds have been shown to be a particularly good geographic focus for vulnerability assessment (Furniss et al. 2010). Scenario planning as a tool for vulnerability assessment has been well developed for forested ecosystems in U.S. national parks (Weeks et al. 2011). Tools developed for setting priorities in forest planning and for assessing risks are especially applicable for near-term decision making (Janowiak et al. 2011a; Morelli et al. 2011b).

Recent comprehensive approaches that incorporate both conceptual strategies and specific tools in guidebooks for developing adaptation strategies (Peterson et al. 2011; Swanston and Janowiak 2012) have proven to be useful for both resource managers and scientists. These guidebooks encourage education and training in the basic climate sciences and describe how to proceed from assessment to on-the-ground practices.

**Box 8.2: Setting Management Goals and Strategies is Necessary to Develop Site-Specific Forest Adaptation Projects (From Swanston and Janowiak 2012)**

**Management Goals** Management goals are broad, general statements that express a desired state or process to be achieved. They are often not attainable in the short term and provide the context for more specific objectives. Examples of management goals include:

- Maintain and improve forest health and vigor.
- Maintain wildlife habitat for a variety of species.

(continued)

(continued)

**Management Objectives** Management objectives are concise, time-specific statements of measurable planned results that correspond to pre-established goals in achieving a desired outcome. These objectives include information on resources to be used for planning that defines precise steps to achieve identified goals. Examples of management objectives include:

- Regenerate a portion of the oldest aspen forest type through clearcut harvest in the next year to improve forest vigor in young aspen stands.
- Identify and implement silvicultural treatments within five years to increase the oak component of selected stands and enhance wildlife habitat.

### *8.3.2 Strategic Steps for Adaptation*

The following steps represent a broad consensus on how to develop forest climate adaptation strategies (Swanston and Janowiak 2012):

**Step 1: Define location (spatial extent), management goals and objectives, and timeframes—**Determine spatial and temporal scales and site-specific locations for appropriate strategies. Management goals and objectives (Box 8.2) for climate adaptation should be explicit and integrated with mitigation and other management goals. Goals are not necessarily stated in narrowly specific quantitative terms; rather, many forest adaptation goals and objectives can be defined broadly (e.g., sustaining ecosystem services).

**Step 2: Analyze vulnerabilities—**Vulnerability to climate change is "the degree to which geophysical, biological, and socio-economic systems are susceptible to, and unable to cope with, adverse impacts of climate change" (Solomon et al. 2007). Vulnerability is a function of the degree to which a system is exposed to a change in climatic conditions, its sensitivity to that change, and its adaptive capacity (IPCC 2001; Gallopín 2006; Solomon et al. 2007). Vulnerability assessments, which can take different forms (Glick et al. 2011; USGCRP 2011), determine how climatic variability and change might affect natural resources, and inform the development of appropriate priorities, strategies, and timeframes for action.

**Step 3: Determine priorities—**Priority actions for climate adaptation may differ from those for traditional forest management, and if conditions are changing rapidly, priorities need to be re-assessed regularly. When conditions are urgent and resources limited (e.g., a species in rapid decline), triage methods can be useful (Joyce et al. 2008). In longer term planning, no-regrets assessments (National Research Council 2002; Overpeck and Udall 2010) minimize risk.

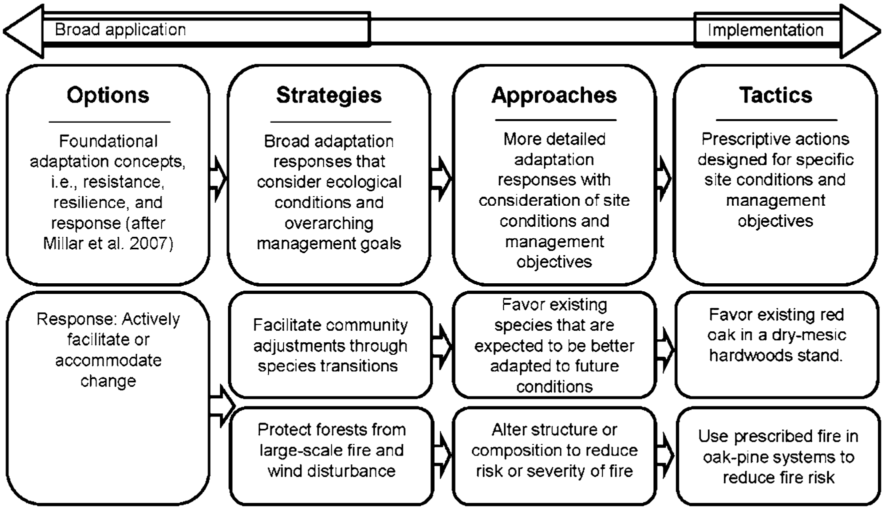


**Fig. 8.2** A continuum of adaptation options to address needs at appropriate scales, and examples of each (*shaded boxes*) (From Janowiak et al. 2011a)

**Step 4: Develop options, strategies, and tactics**—This process begins at a broad conceptual level and steps down to regional and local, site-specific project planning (Swanston and Janowiak 2012), as reflected by the increasing specificity of the following terms (Fig. 8.2). *Adaptation options* are the broadest and most widely applicable level in a continuum of management responses to climate change. Options include resistance, resilience, response, and realignment; they can be short or long term depending on how they are applied (Millar et al. 2007) (Box 8.1), and they can be general or specific and focused on a local situation. *Adaptation strategies* illustrate ways that options can be used. Similar to options, strategies are broad and can be applied in many ways across different forest landscapes (Table 8.4). *Approaches* provide greater detail on how forest managers can respond, with differences in application among specific forest types and management goals becoming evident. *Tactics* are the most specific adaptation response, providing prescriptive direction in how actions are applied on the ground. The culmination of this process is development of a plan, such as a NEPA document or other project plan, prescription, or treatment description.

**Step 5: Implement plans and projects**—Where possible, project implementation should include replication, randomization, and other experimental design elements, which increases the value of the final step.

**Step 6: Monitor, review, adjust**—Adaptive management, a key element in climate-adaptation planning (Baron et al. 2008, 2009; Joyce et al. 2008), involves a comprehensive set of steps developed in an experimental framework. Monitoring is tied to predefined thresholds and other target goals developed to test

**Table 8.4** Climate change adaptation strategies under broad adaptation options

| Strategy | Resistance | Resilience | Response |
|---|---|---|---|
| Sustain fundamental ecological conditions | X | X | X |
| Reduce the impact of existing ecological stressors | X | X | X |
| Protect forests from large-scale fire and wind disturbance | X | | |
| Maintain or create refugia | X | | |
| Maintain or enhance species and structural diversity | X | X | |
| Increase ecosystem redundancy across the landscape | | X | X |
| Promote landscape connectivity | | X | X |
| Enhance genetic diversity | | X | X |
| Facilitate community adjustments through species transitions | | | X |
| Plan for and respond to disturbance | | | X |

From Butler et al. (2012)

hypotheses about project effectiveness and appropriateness; if thresholds are exceeded, plans need to be reviewed and adjusted (Walters 1986; Margoluis and Salafsky 1998; Joyce et al. 2008, 2009). Many constraints exist to effective implementation of adaptive management, but at least some informal monitoring keyed to assessing treatment effectiveness is essential for addressing dynamic conditions driven by climate change.

## 8.4 Tools and Resources for Adaptation and Implementation

Until recently, few guides to implementing climate adaptation plans were available, but many active projects now exist, including in the forest sector. The examples in Table 8.5 are not exhaustive, but represent the type of tools available and the meta-level databases and Web resources that assist in finding relevant tools for specific locations and needs.

## 8.5 Institutional Responses

Executive Order 13514 (2009), "Federal Leadership in Environmental, Energy, and Economic Performance," directs each federal agency to evaluate climate change risks and vulnerabilities to manage the short- and long-term effects of climate change on the agency's mission and operations. An interagency climate change adaptation task force includes 20 federal agencies and develops recommendations for agency actions in support of a national climate change adaptation strategy. Some of the more successful adaptation efforts to date have involved collaboration among different institutions. Collaboration can take many forms, and effective collaborations will differ by landscape and local institutional relationships.

**Table 8.5** Resources that can assist climate change adaptation in forest ecosystems

| | Description | Web site (reference) |
|---|---|---|
| Web sites: Climate Change Resource Center | U.S. Forest Service portal containing comprehensive information and resources relevant to forest resource managers | http://www.fs.fed.us/ccrc (USDA FS 2011a) |
| Climate Adaptation Knowledge Exchange | Knowledge base with an interactive online platform, adaptation case studies, directory of practitioners, and summaries of tools and information from other sites | http://www.cakex.org (CAKE 2011) |
| NaturePeopleFuture.org | The Nature Conservancy (TNC) knowledge base for climate adaptation summarizing adaptation projects, related conservation projects, and adaptation tools | http://conserveonline.org/workspaces/climateadaptation (TNC 2011a) |
| Tribes and Climate Change | Information to help Native people understand climate change and its effects, including information on climate science, tribal engagement in climate change, and resources to assist adaptation | http://www4.nau.edu/tribalclimatechange (NAU 2011) |
| Tools: Climate Wizard | Web-based tool that uses climate projections relevant to the time and space resolution of inquiries, enabling users to visualize modeled changes at several time and spatial scales | http://www.climatewizard.org (TNC 2011b) |
| Vegetation Dynamics Development Tool | User-friendly state-and-transition landscape model for examining the role of various disturbance agents and management actions in vegetation change, allowing users to test sensitivity of vegetation dynamics to climate | http://essa.com/tools/vddt (ESSA 2011) |
| Template for Assessing Climate Change Impacts and Management Options | Web-based tool that connects forest planning to climate change science, providing access to relevant projections and links to scientific literature on climate effects and management options | http://www.forestthreats.org/research/projects/project-summaries/taccimo (North Carolina State University 2011) |
| Climate Project Screening Tool | Verbal interview and priority-setting tool for exploring options that ameliorate the effects of climate in resource projects, allowing managers to assess relative vulnerabilities and anticipate effects of different actions | (Morelli et al. 2011b) |

(continued)

**Table 8.5** (continued)

| | Description | Web site (reference) |
|---|---|---|
| Climate Change Adaptation Workbook | Using a 5-step process, the workbook incorporates regionally specific climate change information in resource management at different spatial scales and levels of decision making | (Janowiak et al. 2011a) |
| System for Assessing Vulnerability of Species | Verbal index tool that identifies relative vulnerability or resilience of vertebrate species to climate change, based on a questionnaire with 22 predictive criteria to create vulnerability scores | (Bagne et al. 2011) |

### *8.5.1 U.S. Forest Service*

The U.S. Forest Service has the best developed national strategy and on-the-ground implementation of adaptation of all federal agencies (USDA FS 2008). They are led by the climate change advisor's office, which develops guidance and evaluates progress toward climate adaptation. Forest Service research and development also has a climate change strategic plan (Solomon et al. 2009). The National Roadmap for Responding to Climate Change (USDA FS 2011b) summarizes tactical approaches and implementation, including 10 steps along four dimensions: agency and organizational capacity, partnerships and conservation education, adaptation, and mitigation (Fig. 8.3). The process includes (1) science-based assessments of risk and vulnerability; (2) evaluation of knowledge gaps and management outcomes; (3) engagement of staff, collaborators, and partners through education, science-based partnerships, and alliances; and (4) management of resources via adaptation and mitigation.

The Climate Change Resource Center (USDA FS 2011a) (Table 8.5) serves as a reference Web site with information and tools to address climate change in planning and project implementation. Climate change coordinators are designated for each Forest Service region and national forest. Current initiatives from research and management branches of the agency provide climate science, develop vulnerability assessments, prepare adaptive monitoring plans, and align planning, policy, and regulations with climate challenges (Box 8.3). The Performance Scorecard (USDA FS 2011c) (Table 8.6) is used to document progress of national forests, regions, and research stations on adaptation plans and "climate smart" actions.

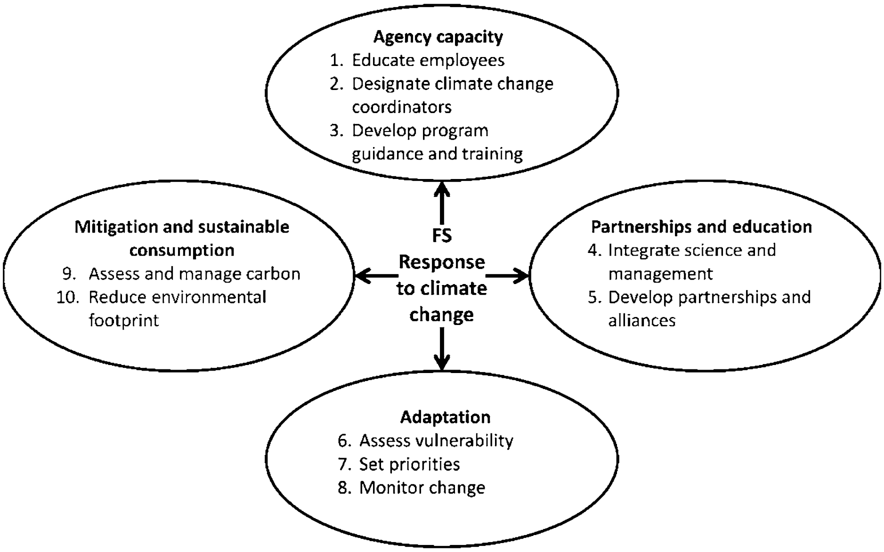


**Fig. 8.3** Four dimensions of action outlined by the U.S. Forest Service roadmap for responding to climate change (From USDA FS 2011b)

**Box 8.3: U.S. Forest Service Initiatives to Promote Progress Toward Achieving Goals of the National Roadmap for Responding to Climate Change (From USDA FS 2011b)**

**Furnish predictive information on climate change and variability**, both immediate and longer term, building on current research capacity and partnerships with the National Oceanic and Atmospheric Administration, National Aeronautics and Space Administration, U.S. Geological Survey, and other scientific agencies

- Develop, interpret, and deliver spatially explicit scientific information on recent shifts in temperature and moisture regimes, including incidence and frequency of extreme events
- Provide readily interpretable forecasts at regional and subregional scales

**Develop vulnerability assessments**, working through research and management partnerships and collaboratively with partners

- Assess the vulnerability of species, ecosystems, communities, and infrastructure and identify potential adaptation strategies
- Assess the impacts of climate change and associated policies on tribes, rural communities, and other resource-dependent communities

(continued)

(continued)

- Collaborate with the U.S. Fish and Wildlife Service and National Marine Fisheries Service to assess the vulnerability of threatened and endangered species and to develop potential adaptation measures

**Tailor monitoring** to facilitate adaptive responses

- Expand observation networks, intensify sampling in some cases, and integrate monitoring systems across jurisdictions (see, for example, the national climate tower network on the experimental forests and ranges)
- Monitor the status and trends of key ecosystem characteristics, focusing on threats and stressors that may affect the diversity of plant and animal communities and ecological sustainability. Link the results to adaptation and genetic conservation efforts

**Align Forest Service policy and direction** with the Forest Service strategic response to climate change

- Revise National Forest System land management plans using guidance established in the Planning Rule, which requires consideration of climate change and the need to maintain and restore ecosystem and watershed health and resilience
- Review Forest Service manuals and other policy documents to assess their support for the agency's strategic climate change direction. Evaluate current policy direction for its ability to provide the flexibility and integration needed to deal with climate change
- Develop proposals for addressing critical policy gaps

### *8.5.2 U.S. Department of the Interior (DOI)*

A U.S. DOI secretarial order (2009) provides a framework to coordinate climate change activities among DOI bureaus and to integrate science and management expertise with DOI partners. Climate Science Centers and Landscape Conservation Cooperatives form the cornerstones of the framework (DOI FWS 2011). Each has a distinct role, but they share complementary capabilities in support of DOI resource managers and of integrated climate solutions with federal, state, local, tribal, and other stakeholders.

The National Park Service (NPS) climate change response strategy (NPS 2010) provides direction for addressing effects of climate change in NPS units. The broad goals of the strategy include developing effective natural resource adaptation

**Table 8.6** Performance scorecard used by the U.S. Forest Service for annual review of progress and compliance, and to identify deficit areas in implementation of the national roadmap for responding to climate change

| Scorecard element | Questions addressed |
|---|---|
| Organizational capacity: | |
| Employee education | Are all employees provided with training on the basics of climate change, impacts on forests and grasslands, and the Forest Service response?<br>Are resource specialists made aware of the potential contribution of their own work to climate change response? |
| Designated climate change coordinators | Is at least one employee assigned to coordinate climate change activities and be a resource for climate change questions and issues?<br>Is this employee provided with the time, training, and resources to make his/her assignment successful? |
| Program guidance | Does the unit have written guidance for progressively integrating climate change considerations and activities into unit-level operations? |
| Engagement: | |
| Science and management partnerships | Does the unit actively engage with scientific organizations to improve its ability to respond to climate change? |
| Other partnerships | Have climate change-related considerations and activities been incorporated into existing or new partnerships (other than science partnerships)? |
| Adaptation: | |
| Assessing vulnerability | Has the unit engaged in developing relevant information about the vulnerability of key resources, such as human communities and ecosystem elements, to the impacts of climate change? |
| Adaptation actions | Does the unit conduct management actions that reduce the vulnerability of resources and places to climate change? |
| Monitoring | Is monitoring being conducted to track climate change impacts and the effectiveness of adaptation activities? |
| Mitigation and sustainable consumption: | |
| Carbon (C) assessment and stewardship | Does the unit have a baseline assessment of C stocks and an assessment of the influence of disturbance and management activities on these stocks?<br>Is the unit integrating C stewardship with the management of other benefits being provided by the unit? |
| Sustainable operations | Is progress being made toward achieving sustainable operations requirements to reduce the environmental footprint of the agency? |

Adapted from USDA FS (2011b, c)

plans and promoting ecosystem resilience, requiring that units (1) develop adaptive capacity for managing natural and cultural resources, (2) inventory resources at risk and conduct vulnerability assessments, (3) prioritize and implement actions and monitor the results, (4) explore scenarios, associated risks, and possible management options, and (5) integrate climate change effects in facilities management. Ecosystem dynamics associated with climate change have forced rethinking of the NPS preservation legacy, and new paradigms are emerging to incorporate ecological change in adaptation philosophies (Cole and Yung 2010; Stephenson and Millar 2012).

The Bureau of Land Management (BLM) focuses on a landscape approach to climate change adaptation, working within ecosystems at large scales and across agency boundaries to assess natural resource conditions and trends, natural and human influences, and opportunities for resource conservation and development. The BLM uses (1) rapid ecoregional assessments (REA), which synthesize information about resource conditions and trends, emphasizing areas of high ecological value (e.g., important wildlife habitats); (2) ecoregional direction, which uses the REAs to identify management priorities for public lands and guide adaptation actions; (3) monitoring for adaptive management, which relies on monitoring and mapping programs to meet understand resource conditions and trends, and evaluate and refine implementation actions; and (4) science integration, which relies on Climate Science Centers to provide management-relevant science. To date, no operational adaptation plans have been produced.

### *8.5.3 Regional Integrated Sciences and Assessment (RISA)*

Funded by the National Oceanographic and Atmospheric Administration's Climate Program Office, the RISA program supports research and stakeholder interaction to improve understanding of climate effects in various regions of the United States, and facilitates the use of climate information in decision making. RISA teams analyze climate data; apply, provide, and interpret climatic information for resource managers and policymakers; and provide information on climate change and regional effects of climate change.

### *8.5.4 State and Local Institutions*

Climate-adaptation responses of state and local institutions are diverse, ranging from minimal action to fully developed and formal programs. State responses that focus on forest-sector issues include the following.

#### 8.5.4.1 Western Governors' Association (WGA)

A nonpartisan organization of governors from 19 Western states, 2 Pacific territories, and 1 commonwealth, the WGA addresses the effects of climate on forest health, wildfire, water and watersheds, recreation, and forest products. The WGA supports integration of climate adaptation science in Western states (WGA 2009) and published a report on priorities for climate response in the West (WGA 2010), including sharing climate-smart practices for adaptation, developing science to be used in decision making, and coordinating with federal entities and other climate adaptation initiatives. The WGA is focusing on developing training to help states incorporate new protocols and strategies relative to climate change, and improving coordination of state and federal climate adaptation initiatives.

#### 8.5.4.2 Washington State Climate Response Strategy

Building on the Washington State Climate Change Impacts Assessment (McGuire et al. 2009; Washington State Department of Ecology 2012), the response strategy is a collaborative effort involving both public and private stakeholders. Recommendations for climate adaptation efforts in major forest ecological systems have been developed (Helbrecht et al. 2011) (Box 8.4), including for fire management and genetic preservation (Jamison et al. 2011). Strategies consistent with adaptation on forest lands include (1) preserve and protect existing working forest, (2) assess how land management decisions help or hinder adaptation, (3) foster interagency collaboration, (4) promote sociocultural and economic relations between eastern and western Washington to improve collaboration, (5) develop options that address major disturbance events, and (6) incorporate state decisions with global and local factors when adapting to climate change (Washington State Department of Ecology 2012).

**Box 8.4: Interim Recommendations for the Washington State Climate Change Response Strategy on Species, Habitats, and Ecosystems (From Helbrecht et al. 2011)**

Facilitate the resistance, resilience, and response of natural systems

- Provide for habitat connectivity across a range of environmental gradients.
- For each habitat type, protect and restore areas most likely to be resistant to climate change.
- Increase ecosystem resilience to large-scale disturbances, including pathogens, invasive species, wildfire, flooding, and drought.
- Address stressors contributing to increased vulnerability to climate change.

(continued)

(continued)

- Incorporate climate change projections in plans for protecting sensitive species.

Build scientific and institutional readiness to support effective adaptation

- Fill critical information gaps and focus monitoring on climate change.
- Build climate change into land use planning.
- Develop applied tools to assist land managers.
- Strengthen collaboration and partnerships.
- Conduct outreach on the values provided by natural systems at risk from climate change.

#### 8.5.4.3 Minnesota State Climate Response

The Minnesota Department of Natural Resources is building intellectual and funding capacity to implement policies that address climate change and renewable energy issues, including vulnerability assessments that identify risks and adaptation strategies for forest ecosystems. The Minnesota Forest Resources Council is developing recommendations to the governor and federal, state, county, and local governments on policies and practices that result in the sustainable management of forest resources. Regional landscape committees establish landscape plans that identify local issues, desired future forest conditions, and strategies to attain these goals (MFRC 2011).

#### 8.5.4.4 North Carolina State Climate Response

The North Carolina Department of Environment and Natural Resources (DENR) is developing an adaptation strategy to identify and address potential effects on natural resources, with emphasis on climate-sensitive ecosystems and land use planning and development. The North Carolina Natural Heritage Program is evaluating likely effects of climate change on state natural resources, including 14 forest ecosystems that are likely to respond to climate change in similar ways. The DENR is coordinating with other agencies on an integrated climate response and climate change response plan.

#### 8.5.4.5 State University and Academic Responses

The University of Washington Climate Impacts Group (CIG) has a strong focus on climate science in the public interest. Besides conducting research and assessing climate effects on water, forests, salmon, and coasts, the CIG applies scientific information in regional decisions (e.g., Snover et al. 2007). The CIG works closely with stakeholders and has been a key coordinator for forest climate adaptation projects (e.g., Halofsky et al. 2011; Littell et al. 2011). The Alaska Coastal Rainforest Center, based at the University of Alaska-Southeast, in partnership with the University of Alaska-Fairbanks and other stakeholders, provides educational opportunities, facilitates research, and promotes learning about temperate rain forests. The center facilitates dialogue on interactions among forest ecosystems, communities, and social and economic. The Center for Island Climate Adaptation and Policy, based at the University of Hawai‘i at Mānoa, promotes interdisciplinary research and solutions to public and private sectors, with a focus on science, planning, indigenous knowledge, and policy relative to climate adaptation. Recent projects focus on education, coordinating with state natural resource departments on adapting to climate change (CICAP 2009), and policy barriers and opportunities for adaptation. Forest-related climate issues include effects of invasive species, forest growth and decline, migration and loss of forest species, and threats to sustainability of water resources.

### *8.5.5 Industrial Forestry*

The response from forest industries in the United States to climate change has to date focused mostly on carbon sequestration, energy conservation, the role of biomass, and other climate-mitigation issues. Detailed assessments and efforts to develop adaptation strategies for forest industry have mostly been at the global to national scale (Sedjo 2010; Seppälä et al. 2009a, b). Many forestry corporations promote stewardship forestry focused on adaptability of forest ecosystems to environmental challenges, but most ongoing adaptation projects are small scale and nascent. For example, Sierra Pacific Industries (SPI) in California is evaluating the potential for giant sequoia (*Sequoiadendron giganteum* [Lindl.] J. Buchholz) plantations to serve as a safeguard against a changing climate. Giant sequoia currently grows in small groves scattered in the Sierra Nevada. Germplasm would be collected by SPI from the native groves and planted in riparian corridors on productive industry land, then managed as reserves that would benefit from the resilience of giant sequoia to climatic variability and its ability to regenerate after disturbance.

### *8.5.6 Native American Tribes and Nations*

Many Native American tribes and nations have been actively developing detailed forest adaptation plans in response to climate change. Overall goals commonly relate to promoting ecosystem sustainability and resilience, restoration of forest ecosystems, and maintenance of biodiversity, especially of elements having historical and legacy significance to tribes. Maintenance of cultural tradition within the framework of changing times is also inherent in many projects.

An exceptional example of a tribal response is the climate change initiative of the Swinomish Tribe in Washington (SITC 2010). The Swinomish Reservation (3,900 ha) is located in northwestern Washington and includes 3,000 ha of upland forest. The initiative focuses on building understanding among the tribal community about climate change effects, including support from tribal elders and external partners. A recent scientific assessment summarizes vulnerabilities of forest resources to climate change, and outlines potential adaptation options (Rose 2010). Tribes have been active partners in collaborative forest adaptation plans. An example is the Confederated Tribes and Bands of the Yakama Nation, whose reservation occupies 490,000 ha in south-central Washington. Tribal lands comprise forest, grazing, and farm lands in watersheds of the Cascade Range. The Yakama Nation has extensive experience in managing dry forest ecosystems and implementing forest action plans, and belongs to the Tapash Sustainable Forest Collaborative, in partnership with the U.S. Forest Service, Washington State Departments of Fish and Wildlife and of Natural Resources, and The Nature Conservancy. The collaborative encourages coordination among landowners to respond to common challenges to natural resources (Tapash Collaborative 2010). Climate change was ranked as a significant threat to forest productivity, leading to a proposal to incorporate specific adaptation strategies and tactics across the Tapash landscape.

### *8.5.7 Nongovernmental Organizations*

Nongovernmental organizations and professional organizations serve a wide range of special interests, and thus respond to climate adaptation challenges in diverse ways.

#### 8.5.7.1 Pacific Forest Trust (PFT)

A nonprofit organization dedicated to conserving and sustaining America's productive forest landscapes, PFT provides support, knowledge, and coordination on private forest lands in the United States. Through its Working Forests, Winning Climate program, PFT has created policy and market frameworks to expand conservation stewardship of U.S. forests to help sustain ecosystem services (PFT 2011). The PFT also supports climate adaptation by working with private forest owners to promote stewardship forestry, whereby forests are managed to provide goods and services that society has come to expect.

#### 8.5.7.2 The Nature Conservancy (TNC)

A science-based conservation organization, TNC has a mission to preserve plants, animals, and natural communities by protecting the lands and waters they need to survive. The TNC climate change adaptation program seeks to enhance the resilience of people and nature to climate change effects by protecting and maintaining ecosystems that support biodiversity and deliver ecosystem services. The program promotes ecosystem-based approaches for adaptation through partnerships, policy strategies for climate adaptation, tools to assist resource managers, and research. The Canyonlands Research Center (Monticello, Utah), a TNC initiative in the Colorado Plateau region, focuses on forest-climate concerns such as woodland ecosystem restoration, invasive species, and effects of drought.

#### 8.5.7.3 Trust for Public Land (TPL)

A conservation organization that helps agencies and communities conserve land for public use and benefit, TPL uses vulnerability assessments, resilience and connectivity data, and other tools to realign its conservation planning at different spatial scales. The TPL is also designing and implementing restoration to enhance the climate resilience of protected tracts. As a member of the Northern Institute of Applied Climate Science, TPL provides guidance to federal and nonfederal partners on strategic planning and on-the-ground management.

#### 8.5.7.4 The Wilderness Society (TWS)

The Wilderness Society leads efforts to fund natural resource adaptation and manage lands so they are more resilient under stresses of climate change, and is a leader in the Natural Resources Adaptation Coalition, which focuses on maintaining and restoring wildlands that include forest wilderness. Specific TWS goals relative to adaptation in forests include (1) restoring native landscapes to increase ecosystem resiliency, (2) protecting rural communities and providing flexibility in wildland fire management, (3) removing invasive species from ecosystems, and (4) repairing damaged watersheds.

### *8.5.8 Ski Industry*

Although not a direct member of the forest sector, the ski industry relies on mountainous terrain, usually forested land leased from federal landowners, and is concerned about reduced snow, rising temperatures, and extreme weather events that may affect the profitability of ski areas. Adaptation options used by the ski industry (Scott and McBoyle 2007) include (1) snowmaking to increase the duration of the ski season (Scott et al. 2006), (2) optimizing snow retention (slope development and operational practices such as slope contouring, vegetation management, and glacier protection), and (3) cloud seeding. Forest vigor and stand conditions within and adjacent to ski area boundaries are important, because forests burned by wildfire or killed by insect outbreaks affect snow retention, wind patterns, and aesthetic value.

## 8.6 Regional Responses

Although general guidance and strategic plans about climate adaptation exist for many land management agencies, strategies for specific places and resource issues are in the early stages. Here we summarize recent efforts to develop forest adaptation strategies for specific locations.

### *8.6.1 Western United States*

#### 8.6.1.1 Olympic National Forest/Olympic National Park (ONFP), Washington

This case study covers a large landscape within a geographic mosaic of lands managed by federal and state agencies, tribes, and private landowners (Littell et al. 2011). The ONFP supports a diverse set of ecosystem services, including recreation, timber, water supply to municipal watersheds, pristine air quality, and abundant fish and wildlife. Management of Olympic National Forest focuses on "restoration forestry," which emphasizes facilitation of late-successional characteristics, biodiversity, and watershed values in second-growth forest. Collaboration with adjoining Olympic National Park, which has a forest protection and preservation mission, is strong. Development of the ONFP adaptation approach employed a science-management partnership, including scientific expertise from the CIG, to implement education, analysis, and recommendations for action. Analysis focused on hydrology and roads, vegetation, wildlife, and fish—a vulnerability assessment workshop for each resource area was paired with a workshop to develop adaptation options based on the assessment. Emphasis in adaptation was on conserving biodiversity while working to restore late-successional forest structure through active management. The process used in the case study has been adopted by local resource managers to incorporate climate change issues in forest plans and projects (Halofsky et al. 2011) and is currently being used to catalyze climate-change education, vulnerability assessment, and adaptation planning across 2.5 million ha in Washington state (North Cascadia Adaptation Partnership 2011; Raymond et al. 2013).

#### 8.6.1.2 Inyo National Forest and Devils Postpile National Monument, California

Inyo National Forest (INF) in eastern California contains Mediterranean and dry forest ecosystems, grading from alpine through forest to shrub-steppe vegetation. Much of the national forest is wilderness with a high degree of biodiversity. Water is scarce, fire and insects are important issues, and recreation is the dominant use of public lands. Devils Postpile National Monument (DEPO) is a small national park unit surrounded by INF lands, and collaboration with INF is strong. Ongoing projects focus on vulnerability of INF resources to climate effects that might affect DEPO, and climate adaptation is a high priority in the DEPO general management plan. A science-management partnership facilitated sharing of knowledge about climate change and effects through targeted workshops (Peterson et al. 2011), and assessment reports developed by scientists (Morelli et al. 2011a) assisted managers in considering climate effects relevant to specific resource responsibilities. For INF, the Climate Project Screening Tool (Morelli et al. 2011b) was developed, providing a screening process to rapidly assess if climate change would affect resources in the queue for current-year management implementation. For DEPO, where ecosystem protection is prioritized, managing the monument as a climate refugium (Joyce et al. 2008; Peterson et al. 2011) is being evaluated. Because DEPO is at the bottom of a large canyon with cold-air drainage, it contains high biodiversity, and the potential for cold-air drainage to increase in the future may ameliorate the effects of a warmer climate (Daly et al. 2009).

#### 8.6.1.3 Shoshone National Forest, Wyoming

Resource managers in Shoshone National Forest worked with Forest Service scientists to write a synthesis on climate change effects and a vulnerability assessment of key water and vegetation resources. The synthesis (Rice et al. 2012) describes what is currently understood about local climate and the surrounding Greater Yellowstone Ecosystem and how future climate change may affect local ecosystems. The assessment highlights components of local ecosystems considered most vulnerable to projected changes in climate and will be integrated in resource-related decision making processes of forest management through collaborative workshops to train managers.

#### 8.6.1.4 The Strategic Framework for Science in Support of Management in the Southern Sierra Nevada, California (SFS)

The SFS addresses collaborative climate adaptation for the southern Sierra Nevada bioregion of California (Nydick and Sydoriak 2011), including the southern and western slopes of the Sierra Nevada, three national parks, a national monument, three national forests, tribal lands, state and local public lands, forest industry, and other private lands. This landscape spans ecosystems from alpine through diverse conifer and hardwood forests to woodland and chaparral. The effort is coordinated by a coalition of federal resource managers and academic and agency scientists, and was launched with a public symposium to review the state of science on climate issues and adaptation options. Interactions among climate change and habitat fragmentation, encroaching urbanization, shifting fire regimes, invasive species, and increasing air pollution are important issues in this region. The SFS collaborative has generated a list of ideas to provide knowledge and tools regarding agents of change and potential responses, and a framework document (Exline et al. 2009) is being used to guide adaptation.

### *8.6.2 Southern United States*

Uwharrie National Forest (North Carolina) (UNF) represents a typical national forest context in the southeastern United States, containing 61 parcels mixed with private land and near metropolitan areas (Joyce et al. 2008). Providing a wide range of ecosystem services, the region is undergoing a rapid increase in recreational demand. The UNF identified forest mortality, wildfire, insect outbreaks, soil erosion, stream sedimentation, and water shortages as key issues relative to climate effects. Revision of the forest plan explicitly considers climate change effects. Opportunities for adaptation in UNF focus on reestablishing longleaf pine (*Pinus palustris* Mill.) through selective forest management (Joyce et al. 2008). Replanting of drought-tolerant species could provide increased resistance to potential future drought and intense wildlife. Selective harvest and prescribed burns also could target restoration of longleaf pine savannas, mitigating water stress, fuel loads, and wildfire risk anticipated under warming conditions.

### *8.6.3 Northern United States*

The U.S. Forest Service in the Northeast and upper Midwest is pursuing a comprehensive program of adaptation to climate change (Fig. 8.4), including education and training, partnership building, vulnerability assessment and synthesis, planning and decision support, and implementation of demonstration projects. The Forest Service Northern Research Station, Northeastern Area State and Private Forestry, and Northern Institute of Applied Climate Science work collectively to respond to climate change needs. The Climate Change Response Framework (CCRF) developed by these entities augments the institutional capacity of national forests to adapt to climate change by providing a model for collaborative management and climate change response that can accommodate multiple locations, landscapes, and organizations (Fig. 8.5).

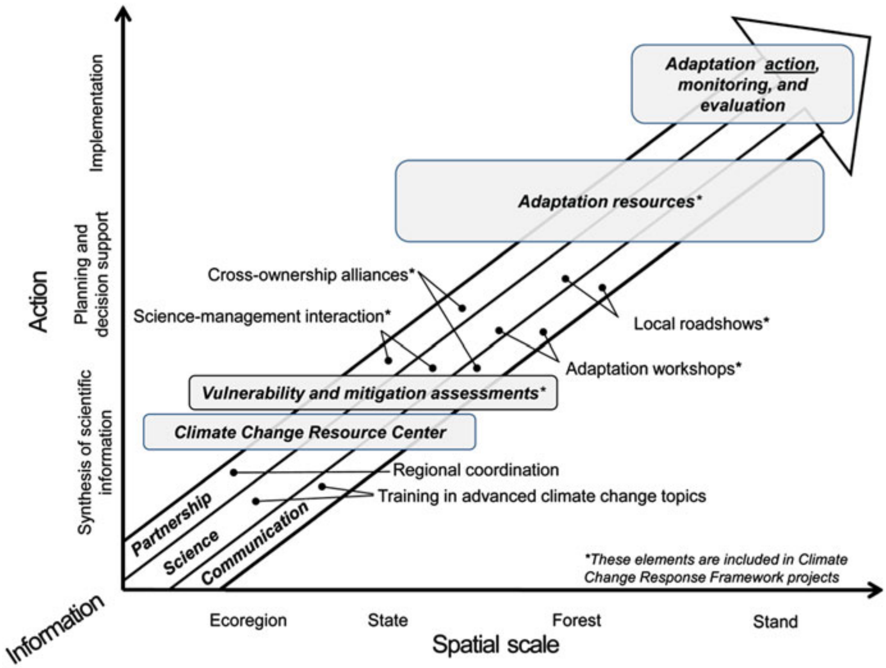


**Fig. 8.4** The U.S. Forest Service Eastern Region approach to climate change response works from ecoregional scales down to the stand scale by moving information to action through partnerships, science, and communication

Individual projects focus on building science-management partnerships, developing vulnerability assessments and synthesis of existing information, and establishing a standardized process for considering management plans and activities in the context of the assessment. First, an ecosystem vulnerability assessment and synthesis evaluates ecosystem vulnerabilities and management implications under a range of plausible future climates. Second, a shared landscape initiative promotes dialogue among stakeholders and managers about climate change, ecosystem response, and management. Third, a science team encourages rapid dissemination of information. Fourth, an adaptation resources document includes relevant strategies and a process for managers to devise appropriate tactics. Fifth, demonstration projects incorporate project information and tools in adaptation activities. The CCRF emphasizes an all-lands approach, including national forests, other agencies, and other landowners and stakeholders.

The Northwoods CCRF Project covers 26 million ha of forest in Michigan, Minnesota, and Wisconsin, including six national forests, the Forest Service Northern Research Station, state resource agencies, universities, and other stakeholders. Products to date focus on northern Wisconsin, including a vulnerability assessment (Swanston et al. 2011), a forest adaptation resources document (Swanston and Janowiak 2012), and initiation of demonstration projects in Chequamegon-Nicolet

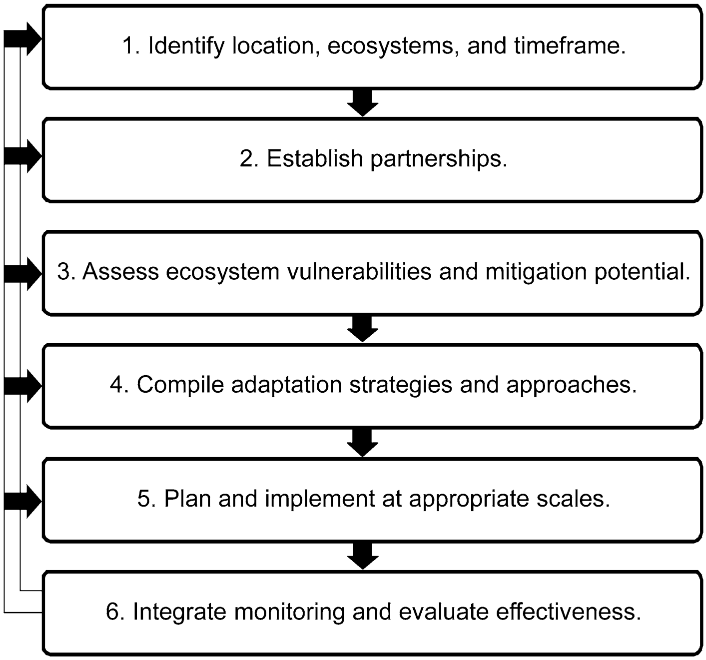


**Fig. 8.5** The Climate Change Response Framework uses an adaptive management approach to help land managers understand the potential effects of climate change on forest ecosystems and integrate climate change considerations into management (From Swanston et al. 2012)

National Forest, where each district was asked to integrate climate change considerations into forest activities. The Central Hardwoods CCRF, which covers 17 million ha of hardwood forest in Missouri, Illinois, and Indiana, has formed a regional coordinating team with partners from three national forests, the Northern Research Station, and other stakeholders. The Central Appalachians CCRF, which covers 11 million ha of central Appalachian forest in West Virginia and Ohio, includes partners from two national forests and state forestry agencies.

### *8.6.4 National Example—Watershed Vulnerability Assessment*

In 2010, a watershed vulnerability assessment process was tested in 11 national forests (Furniss et al. 2010, 2013), with the goal of quantifying current and projected future condition of watersheds as affected by climate change. These forests developed a general process that can be tailored to local data availability and resource investment (Box 8.5). Design of useful strategies for reducing the effects of climate change on ecosystem services requires the ability to (1) identify watersheds of highest priority for protecting amenity values, (2) identify watersheds in which climate-related risk to those values is greatest and least, (3) detect evidence of the magnitudes of change as early as possible, and (4) select actions appropriate for reducing effects in particular watersheds (Peterson et al. 2011).

Hydrologic specialists from participating forests developed an approach for quantifying watershed vulnerability within a relatively short period, and four national forests completed the process within 8 months. Acquiring suitable climate exposure data (the magnitude of deviation in climate that a system experiences), which had not been previously used by the participants, was challenging. Threshold values for species and water use differed across the forests. For example, brook trout (*Salvelinus fontinalis* Mitchill) was viewed as a stressor in one forest and a valued resource in another. These differences suggest that, whereas information on processes and resource conditions can be shared among forests, local (forest- and watershed-scale) assessments have the greatest value.

**Box 8.5: Steps Defining the Watershed Vulnerability Assessment Process and the Types of Questions to be Addressed (From Furniss et al. 2010)**

**Step 1—**Set up the analysis and establish the scope and water resource values that will drive the assessment
**Step 2—**Assess exposure
**Step 3—**Assess sensitivity
**Step 4—**Evaluate and categorize vulnerability
**Step 5—**Recommend responses
**Step 6—**Critique the vulnerability assessment

Typical questions to be addressed in a watershed vulnerability assessment:

- Which places are vulnerable?
- Which places are resilient?
- Where are the potential refugia?
- Where will conflicts arise first, and worst?
- Which factors can exacerbate or ameliorate local vulnerability to climate change?
- What are the priorities for adaptive efforts?
- How can context-sensitive adaptations be designed?
- What needs tracking and monitoring?

## 8.7 Assessment: Challenges and Opportunities

### *8.7.1 Assessing Adaptation Response*

In recent years, several organizations have produced climate change response strategies that define adaptation goals and describe a framework for action in field units. These strategies, intended to inform and guide consistent agency-wide responses, emphasize (1) staff training and education in climate sciences, (2) science-management partnerships, (3) assessment of vulnerabilities and risks, (4) maintenance of ecosystem sustainability and biodiversity conservation, (5) integration of climate challenges with other forest disturbance agents and stressors, (6) integration of adaptation with greenhouse gas mitigation, (7) all-lands and collaborative approaches (working with whole ecosystems and across jurisdictional borders), (8) recognition of short- and long-term planning perspectives, (9) setting priorities, and (10) monitoring and adaptive management.

Adaptation strategies have been advanced unevenly by federal agencies at regional and local levels (e.g., national forests and national parks). Successful implementation in individual management units has been facilitated by motivated leaders, support from local leadership, and the involvement of constituencies. Some units have worked with local scientists to analyze regional climate projections, develop ecosystem vulnerability assessments, and develop intellectual capacity through staff and constituency education. Collaborative partnerships that extend across ownerships and jurisdictions have been developed as a foundation for some adaptation projects, promoting communication across ownerships. A few progressive units have implemented climate adaptation projects on the ground, but only a few site-specific adaptation projects, as described above, have been accomplished and tiered to local and regional strategies. Responses of state governments have also been variable, with forest-sector states in the western and northern United States leading the way with adaptation strategies. As with federal agencies, concepts and frameworks for adaptation are sometimes available, but site-specific projects are rare. Adaptation responses by tribes and nongovernmental organizations have focused on education, vulnerability assessments, collaborative partnerships, and biodiversity protection, but again with limited on-the-ground activity.

Some organizations have made progress on adaptation by considering climate response strategies as equal or subordinate to more established objectives of ecosystem sustainability, forest and watershed restoration, and biodiversity conservation. Therefore, climate change is not perceived as a primary driver, or even a "lightning rod" issue, and adaptation goals can be accomplished through projects that address high-priority management goals, such as management of fuels, invasive species, insects, and watershed condition.

Implementation of site-specific adaptation plans has been uneven and often superficial across the forest sector, often failing to corroborate the output of climate models and ecosystem response models with local ecosystems (Millar et al. 2007). A subtle danger in using complex, downscaled models is that users may accept model output as a single future, rather than one of several possible outcomes. It is preferable to use models to understand processes and cautiously project climate and ecosystem responses for specific landscapes and time scales, then develop adaptation options for those outcomes.

### *8.7.2 Adaptation Challenges*

Numerous barriers have made it difficult for forest management organizations to develop and implement plans that would promote widespread preparation of U.S. forests for a warmer climate. We view these barriers as challenges that need to be addressed as quickly as possible.

#### 8.7.2.1 Education, Awareness, and Empowerment

University curricula now include courses on climate science, ecosystem responses to climate change, and implications for resource management. Connecting these relatively new educational curricula with historical climatology would improve understanding of concepts like “100-year floods” or “restoration to historic conditions,” that assume stationary long-term conditions. Development of appropriate management responses to climate change will need to incorporate a more dynamic perspective on climate and ecosystems (Milly et al. 2008). In general, if resource managers acquire a better understanding of climate science, they will have greater confidence in taking management action. Even if resource managers are knowledgeable about climate science, they may lack support from leadership to implement adaptation, so organizations will benefit if climate education propagates through the highest levels.

Despite widespread public engagement in land management over the past 30 years, pressure to act on climate change has not been as prominent as for other resource issues. Minimal support exists for implementing adaptation projects, and opposition often exists to projects that address indirect effects of climate, such as forest thinning, postfire logging, and road improvements for watershed protection. Reaching out to the public with educational programs on climate change may improve local support for adaptation planning and management.

#### 8.7.2.2 Policy, Planning, and Regulations

Both public and private lands are subject to policy, planning, and regulatory direction. Federal agencies are constrained by hierarchies of laws and internal policy and direction, whereas private forest landowners have greater flexibility to determine actions on their land but are still bound by local, state, and federal laws. In federal agencies, site-specific projects are tiered to levels of planning at higher levels in the organization.

In national forests, site-specific projects tier to each forest's land management plan, which guide management activities to ensure that sustainable management considers the broader landscape and resource values. The U.S. Forest Service has developed procedures through a new national planning rule (Federal Register vol. 76, no. 30; 36 CFR Part 219) to amend, revise, and develop land management plans. The planning rule gives the Forest Service the ability to complete plan revisions more quickly and reduce costs, while using current science, collaboration, and an all-lands approach to produce better outcomes for federal lands and local communities. The planning rule enables management in the context of climate change and other stressors, requiring plans to address maintenance and restoration of ecosystem health and resilience, protection of key resources (e.g., water, air, and soil), and protection and restoration of water quality and riparian areas.

Facing the challenge of working at spatial and temporal scales compatible with climate change requires integration of goals and projects from small to large scales, which may be challenging across a mix of ownerships, making collaboration among multiple organizations essential. As noted above, progress has been made by collaborative efforts that overcame perceived barriers in the regulatory and policy environment. Even at small scales, such as a single national forest or national park, traditional planning approaches dissect lands into discrete units, subject to standards and guidelines for each type of management unit (e.g., watershed protection, timber harvest, wilderness). A more flexible approach that works across the current land classification and regulatory environment will be more compatible with the dynamism of climate and ecosystem responses.

Most environmental laws developed over the past 40 years assume climatic stationarity and thus lack capacity (or legal authority) to accommodate dynamic climate-related changes. For example, endangered species laws often reference native species ranges prior to Euro-American settlement. Climate change will likely catalyze range shifts that will define new native ranges, and enforced maintenance of species in the prior range could be counteradaptive. The National Forest Management Act (NFMA 1976) implies maintenance of the status quo based on historical conditions, usually defined as pre-settlement (nineteenth century) ranges. Because regeneration is the most effective period for changing forest trajectories, planting nursery stock from outside the current seed zone, non-traditional mixes of species, or new species might be a defensible adaptation response (Joyce et al. 2008).

#### 8.7.2.3 Monitoring and Adaptive Management

Future climates and environmental conditions will likely be different than the past, and the imprint of human land use has fragmented and altered forest ecosystems for over a century, making it difficult to determine which forest conditions might be "natural" or "normal." Forest adaptation can meet this challenging set of conditions with innovative approaches informed by monitoring and adaptive management ("learn as you go"). Unfortunately adaptive management in public agencies has been implemented slowly, owing to lack of funding commitment. Modifying objectives and issues to include climate change will be required for monitoring and adaptive management to be a successful partner with adaptation.

#### 8.7.2.4 Financial Barriers

Significant additional funding will be needed for a full national response to forest climate adaptation. Education and training, development of science-management partnerships, vulnerability assessments, and development of adaptation strategies can in many cases be integrated with other aspects of management, although effective consideration of climate requires additional time and effort. Collaboration across organizations and leveraging of institutional capacities can improve efficiency and stretch budgets, allowing at least some progress to be made in landscapes that may be regarded as particularly sensitive to climate change.

### *8.7.3 A Vision for Climate Smart Forest Management*

Facilitating long-term sustainability of ecosystem function is the foundation of climate change adaptation. Effective climate change adaptation will differ by ecosystem, management goals, human community, and regional climate. If adaptation is addressed in a piecemeal fashion (ecological, geographic, and social), some components of the forest sector may suffer the consequences of slow response and inefficiencies. We offer a vision of successful adaptation across U.S. forests within the next 20 years, guided by the statement "A proactive forest sector makes the necessary investments to work across institutional and ownership boundaries to sustain ecosystem services by developing, sharing, and implementing effective adaptation approaches." The following actions are needed to accomplish this vision:

- **Investment—**Invest in (1) basic and applied research; (2) adequate staffing to accommodate increased planning, monitoring complexity, and interaction with partners; and (3) internal and external communication on the dynamic nature of climate and forests. Share monitoring data across multiple agencies and ownerships. Support resource centers, instructional courses, and professional meetings that encourage rapid communication of adaptation management and science. Ensure that planning and other functions facilitate the implementation of on-the-ground activities.
- **Development—**Continue research on forest ecosystem sciences to provide insights into forest responses to climate change, including the effectiveness of climate-adaptation strategies and policies. Update relevant information that allows resource managers to (1) assess vulnerability of ecosystem components,

(2) incorporate a range of climate projections, (3) use multiple modeling approaches to project ecosystem response, and (4) incorporate skills and experience of scientists and land managers. Institutionalize active learning through (1) adaptive management trials that evaluate adaptation techniques, (2) working forests, especially national forests, that serve as "living laboratories" for testing adaptation techniques, and (3) documentation of broad landscape conditions and trends.

- **Sharing—**Clearly state management goals in forest planning documents, including options for sustaining ecosystem function under a range of plausible future climates. Identify vulnerable ecosystems and ecosystem components in vulnerability assessments and management plans, clearly state adaptation options, and identify in potential risks to ecosystem services. Increase investment in local programs that assist small landowners. Share climate information across boundaries of public and private lands, and encourage collaborative management across administrative and ownership boundaries. Institutionalize science-management partnerships to ensure long-term dialogue and collaboration around climate change science and practice.
- **Implementation—**Incorporate climate change in planning activities, and adjust on-the-ground prescriptions to include adaptation where necessary. Provide feedback to the scientific community with feedback on the relevance and clarity of tools and information. Integrate monitoring across multiple scales and institutions, and identify indicators that are sensitive to changes in key ecosystem components, and provide a link from monitoring to decision making. Include the increased potential of extreme events and novel climates in management plans, and ensure that decision making can accommodate multiple potential futures. Use active management to promote resistance and resilience where appropriate, managing some forests to "soften the landing" as they transition to new species assemblages and forest structures. Quickly restore forests affected by extreme events, considering the potential effects of climate on species composition and ecological processes.

We are confident that the U.S. forest sector can make significant progress toward a vision of sustained forest ecosystem function in the face of climate change. This can be accomplished by embracing education and communication about the central role of climatic dynamics in ecosystem processes for resource professionals, stakeholders, and the general public. Accountability for infusing climate into all organizational efforts will ensure that management plans, projects, and decisions are "climate smart." Knowledge about climate is not an independent staff area, but a context through which resource issues can be evaluated. An all-lands approach to climate change and forest management will make collaboration is the norm, ensuring diverse organizational and social perspectives. "Early adapter" collaborations show how regulations, traditions, cultures, and organizational legacies can be navigated successfully. Organizations need to be nimble and flexible to develop effective adaptive responses to climatic challenges. A more streamlined planning process will ensure that projects are implemented in a timely way; planning that prioritizes project implementation including uncertainty, risk, and provisions for experimentation will have the most success.

The challenge of climate change adaptation will require creativity by future generations of forest resource managers. No one agency or organization can fully meet the challenge, but this task is within reach if willing partners work collaboratively toward sustainable management grounded in knowledge of climate science and dynamic ecosystems.

## References


Aubry, C., Devine, W., Shoal, R., et al. (2011). *Climate change and forest biodiversity: A vulnerability assessment and action plan for national forests in western Washington* (310 p). Portland: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. http://ecoshare.info/wp-content/uploads/2011/05/CCFB.pdf

Bagne, K. E., Friggens, M. M., Finch, D. M. (2011). *A system for assessing vulnerability of species (SAVS) to climate change* (General Technical Report RMRS-GTR-257, 28 p). Fort Collins: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. http://www.treesearch.fs.fed.us/pubs/37850

Baron, J. S., Allen, C. D., Fleishman, E., et al. (2008). National parks. In S. H. Julius & J. M. West (Eds.), *Preliminary review of adaptation options for climate-sensitive ecosystems and resources: A report by the U.S. Climate Change Science Program and the subcommittee on Climate Change Research* (pp. 4-1–4-68). Washington, DC: U.S. Environmental Protection Agency.

Baron, J. S., Gunderson, L., Allen, C. D., et al. (2009). Options for national parks and reserves for adapting to climate change. *Environmental Management, 44*, 1033–1042.

Butler, P. R., Swanston, C. W., Janowiak, M. K., et al. (2012). Adaptation strategies and approaches. In C. W. Swanston & M. K. Janowiak (Eds.), *Forest adaptation resources: Climate change tools and approaches for land managers* (General Technical Report NRS-87, pp. 15–34). Newtown Square: U.S. Department of Agriculture, Forest Service, Northern Research Station.

Carter, T. R., Parry, M. L., Harasawa, H., & Nishioka, S. (1994). *IPCC technical guidelines for assessing climate change impacts and adaptation. Working group 2 of the Intergovernmental Panel on Climate Change* (pp. 1–72). Cambridge: Cambridge University Press.

Cayan, D. R., Maurer, E. P., Dettinger, M. D., et al. (2008). Climate change scenarios for the California region. *Climatic Change, 87*, S21–S42.

Center for Island Climate Adaptation and Policy [CICAP]. (2009). *A framework for climate change adaptation in Hawaii* (30 p). Honolulu: State of Hawaii, Ocean Resources Management Plan Working Group; University of Hawaii, Center for Island Climate Adaptation and Policy.

Clean Air Act of 1970; 42 U.S.C. s/s 7401 et seq.

Clean Water Act of 1977; 33 U.S.C. s/s 1251 et seq.

Climate Adaptation Knowledge Exchange [CAKE]. (2011). CAKE: Climate adaptation knowledge exchange. http://www.cakex.org. 28 Dec 2011.

Cole, D. N., & Yung, L. (2010). *Beyond naturalness: Rethinking park and wilderness stewardship in an era of rapid change* (304 p). Washington, DC: Island Press.

Crook, J. A., & Forster, P. M. (2011). A balance between radiative forcing and climate feedback in the modeled 20th century temperature response. *Journal of Geophysical Research, 116*, D17108.

Daly, C., Conklin, D. R., & Unsworth, M. H. (2009). Local atmospheric decoupling in complex topography alters climate change impacts. *International Journal of Climatology, 30*, 1857–1864.

Daniels, A. E., Morrison, J. F., Joyce, L. A., et al. (2012). *Climate projections FAQ* (General Technical Report RMRS-GTR-277WWW, 32 p). Fort Collins: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Endangered Species Act of 1973 [ESA], 16 U.S.C. 1531–1536, 1538–1540.

ESSA. (2011). Vegetation dynamics development tool (VDDT). http://essa.com/tools/vddt. 28 Dec 2011.

Exec. Order No. 13,514, 74 Fed. Reg. 194, 52117 (2009, October 8). Federal leadership in environmental, energy, and economic performance. http://www.whitehouse.gov/administration/eop/ceq/sustainability. 28 Dec 2011.

Exline, J., Graber, D., Stephenson, N., et al. (2009). *A strategic framework for science in support of management in the Southern Sierra Nevada ecoregion: A collaboratively developed approach* (24 p). Three Rivers: Southern Sierra Nevada Ecoregion. http://www.nps.gov/seki/naturescience/upload/strategic-framework-2.pdf. 27 Dec 2011.

Furniss, M. J., Roby, K. B., Cenderelli, D., et al. (2013). *Assessing the vulnerability of watersheds to climate change* (General Technical Report PNW-GTR-884, 308 p). Portland: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Furniss, M. J., Staab, B. P., Hazelhurst, S., et al. (2010). *Water, climate change, and forests: Watershed stewardship for a changing climate* (General Technical Report GTR-PNW-812, 75 p). Portland: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Gallopín, G. C. (2006). Linkages between vulnerability, resilience, and adaptive capacity. *Global Environmental Change, 16*, 293–303.

Glick, P., Stein, B. A., Edelson, N. A., (Eds.). (2011). *Scanning the conservation horizon: A guide to climate change vulnerability assessment* (176 p). Washington, DC: National Wildlife Federation. http://www.nwf.org/vulnerabilityguide. 27 Dec 2011.

Halofsky, J. E., Peterson, D. L., O'Halloran, K. A., & Hawkins Hoffman, C. (2011). *Adapting to climate change at Olympic National Forest and Olympic National Park* (General Technical Report PNW-GTR-844, 130 p). Portland: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Harris, J. A., Hobbs, R. J., Higgs, E., & Aronson, J. (2006). Ecological restoration and global climate change. *Restoration Ecology, 14*, 170–176.

Helbrecht, L., Jackson, A., Speaks, P., co-chairs. (2011). *Washington State climate change response strategy: Interim recommendations from Topic Advisory Group 3 on species, habitats and ecosystems*. (Topic Advisory Group 3 interim report, February 2011, 95 p). Olympia: State of Washington, Department of Ecology.

Intergovernmental Panel on Climate Change [IPCC]. (2001). *Climate change 2001: Mitigation. Third assessment report of the Intergovernmental Panel on Climate Change, Working Group III* (753 p). Cambridge: Cambridge University Press.

Jackson, S. T. (2012). Conservation and resource management in a changing world: Extending historical range of variation beyond the baseline. In J. Wiens, C. Regan, G. Hayward, & H. Safford (Eds.), *Historical environmental variation in conservation and natural resource management* (pp. 92–110). New York: Springer.

Jamison, R., Cook, K., Sandison, D., co-chairs. (2011). *Washington state integrated climate change response strategy: Interim recommendations of the natural resources: Working lands and water topic advisory group*. http://www.ecy.wa.gov/climatechange/2011TAGdocs/R2011_interimreport.pdf

Janowiak, M. K., Butler, P. R., Swanston, C. W., et al. (2011a). Adaptation workbook. In C. W. Swanston & M. K. Janowiak (Eds.), *Forest adaptation resources: Climate change tools and approaches for land managers* (General Technical Report NRS-87, pp. 35–56). Newtown Square: U.S. Department of Agriculture, Forest Service, Northern Research Station. Chapter 3.

Janowiak, M. K., Swanston, C. W., Nagel, L. M., et al. (2011b). *Silvicultural decision-making in an uncertain climate future: A workshop-based exploration of considerations, strategies, and approaches* (General Technical Report NRS-81, 14 p). Newtown Square: U.S. Department of Agriculture, Forest Service, Northern Research Station.

Johnstone, M., & Williamson, T. (2007). A framework for assessing climate change vulnerability of the Canadian forest sector. *The Forestry Chronicle, 83*, 358–361.

Joyce, L. A., Blate, G. M., Littell, J. S., et al. (2008). National forests. In S. H. Julius & J. M. West (Eds.), *Preliminary review of adaptation options for climate-sensitive ecosystems and resources: A report by the U.S. Climate Change Science Program and the Subcommittee on Climate Change Research* (pp. 3-1–3-127). Washington, DC: U.S. Environmental Protection Agency. Chapter 3.

Joyce, L. A., Blate, G. M., McNulty, S. G., et al. (2009). Managing for multiple resources under climate change. *Environmental Management, 44*, 1022–1032.

Kohm, K. A., Franklin, J. F., (Eds.). (1997). *Creating a forestry for the 21st century: The science of ecosystem management* (475 p). Washington, DC: Island Press.

Lackey, R. T. (1995). Seven pillars of ecosystem management. *Landscape and Urban Planning, 40*, 21–30.

Lindner, M., Maroschek, M., Netherer, S., et al. (2010). Climate change impacts, adaptive capacity, and vulnerability of European forest ecosystems. *Forest Ecology and Management, 259*, 698–709.

Littell, J. S., & Peterson, D. L. (2005). A method for estimating vulnerability of Douglas-fir growth to climate change in the northwestern U.S. *The Forestry Chronicle, 81*, 369–374.

Littell, J. S., Oneil, E. E., McKenzie, D., et al. (2010). Forest ecosystems, disturbance, and climatic change in Washington State, USA. *Climatic Change, 102*, 129–158.

Littell, J. S., Peterson, D. L., Millar, C. I., & O'Halloran, K. A. (2011). U.S. National forests adapt to climate change through science-management partnerships. *Climatic Change, 110*, 269–296.

Margoluis, R., Salafsky, N. (1998). *Measures of success: Designing, managing, and monitoring conservation and development projects* (384 p). Washington, DC: Island Press.

McGuire, E. M., Littell, J., Whitely Binder, L., (Eds.). (2009). *The Washington climate change impacts assessment* (414 p). Seattle: University of Washington, Center for Science in the Earth System, Joint Institute for the Study of the Atmosphere and Oceans, Climate Impacts Group.

McKenney, D., Pedlar, J., & O'Neill, G. (2009). Climate change and forest seed zones: Past trends, future prospects and challenges to ponder. *The Forestry Chronicle, 85*, 258–266.

McLachlan, J. S., Hellmann, J. J., & Schwart, M. W. (2007). A framework for debate of assisted migration in an era of climate change. *Conservation Biology, 21*, 297–302.

Metz, B., Davidson, O., Swart, R., Pan, J., (Eds.). (2001). *Climate change 2001: Mitigation. Contribution of Working Group III to the third assessment report of the Intergovernmental Panel on Climate Change* (700 p). Cambridge: Cambridge University Press.

Millar, C. I., Stephenson, N. L., & Stephens, S. L. (2007). Climate change and forests of the future: Managing in the face of uncertainty. *Ecological Applications, 17*, 2145–2151.

Milly, P. C. D., Betancourt, J., Falkenmark, M., et al. (2008). Stationarity is dead: Whither water management? *Science, 319*, 573–574.

Minnesota Forest Resources Council [MFRC]. (2011). *Landscape management documents*. http://www.frc.state.mn.us/resources_documents_landscape.html. 28 Dec 2011.

Morelli, T. L., McGlinchy, M. C., & Neilson, R. P. (2011a). *A climate change primer for land managers: An example from the Sierra Nevada* (Research Paper PSW-RP-262, 44 p). Albany: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station.

Morelli, T. L., Yeh, S., Smith, N., et al. (2011b). *Climate project screening tool: An aid for climate change adaptation* (Research Paper PSW-RP-263, 29 p). Albany: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station.

Moser, S. C., & Luers, A. L. (2008). Managing climate risks in California: The need to engage resource managers for successful adaptation to change. *Climatic Change, 87*, S309–S322.

National Environmental Policy Act of 1969 [NEPA]; 42 U.S.C. 4321 et seq.

National Forest Management Act of 1976 [NFMA]. (1976). Act of October 22, 1976; 16 U.S.C. 1600.

National Park Service [NPS]. (2010). *Climate change response strategy: Science, adaptation, mitigation, communication* (26 p). Fort Collins/Washington, DC: U.S. Department of the Interior, National Park Service, Climate Change Response Program/U.S. Department of the Interior, National Park Service.

National Research Council, Committee on Abrupt Climate Change. (2002). *Abrupt climate change: Inevitable surprises* (230 p). Washington, DC: National Academy Press.

Nitschke, C. R., & Innes, J. L. (2008). Integrating climate change into forest management in south-central British Columbia: An assessment of landscape vulnerability and development of a climate-smart framework. *Forest Ecology and Management, 256*, 313–327.

North Carolina State University [NCSU]. (2011). *TACCIMO: Template for assessing climate change impacts and management options*. http://www.sgcp.ncsu.edu:8090

North Cascadia Adaptation Partnership. (2011). *North Cascadia Adaptation Partnership: Preparing for climate change through science-management collaboration*. http://northcascadia.org

Northern Arizona University [NAU]. (2011). *Tribes and climate change*. http://www4.nau.edu/tribalclimatechange

Nydick, K., & Sydoriak, C. (2011). The strategic framework for science in support of management in the Southern Sierra Nevada, California. *Park Science, 28*, 41–43.

Overpeck, J., & Udall, B. (2010). Dry times ahead. *Science, 328*, 1642–1643.

Pacific Forest Trust [PFT]. (2011). *Working forests, winning climates*. http://www.pacificforest.org/Working-Forests-Winning-Climate.html. 27 Dec 2011.

Peterson, D. L., Parker, V. T., (Eds.). (1998). *Ecological scale: Theory and applications* (608 p). New York: Columbia University Press.

Peterson, D. L., Millar, C. I., Joyce, L. A., et al. (2011). *Responding to climate change on national forests: A guidebook for developing adaptation options* (General Technical Report PNW-GTR-855, 109 p). Portland: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Potter, K. M., & Crane, B. S. (2010). *Assessing forest tree genetic risk across the southern Appalachians: A tool for conservation decision-making in changing times*. http://www.forestthreats.org/current-projects/project-summaries/genetic-risk-assessment-system.

Raymond, C. L., Peterson, D. L., & Rochefort, R. M. (2013). The North Cascadia adaptation partnership: A science-management collaboration for responding to climate change. *Sustainability, 5*, 136–159.

Ricciardi, A., & Simberloff, D. (2009). Assisted colonization is not a viable conservation strategy. *Trends in Ecology and Evolution, 24*, 248–253.

Rice, J., Tredennick, A., & Joyce, L. A. (2012). *Climate change on the Shoshone National Forest, Wyoming: A synthesis of past climate, climate projections, and ecosystem implications* (General Technical Report RMRS-GTR-264, 60 p). Fort Collins: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Rose, K. A. (2010). *Tribal climate change adaptation options: A review of the scientific literature* (86 p). Seattle: U.S. Environmental Protection Agency, Region 10, Office of Air, Waste and Toxics.

Scott, D., & McBoyle, G. (2007). Climate change adaptation in the ski industry. *Mitigation and Adaptation Strategies for Global Change, 12*, 1411–1431.

Scott, D., McBoyle, G., Minogue, A., & Mills, B. (2006). Climate change and the sustainability of ski-based tourism in Eastern North America: A reassessment. *Journal of Sustainable Tourism, 14*, 376–398.

Sedjo, R. (2010). *Adaptation of forests to climate change: Some estimates* (Discussion Paper RFF DP 10-06, 51 p). Washington, DC: Resources for the Future.

Seppälä, R., Buck, A., & Katila, P. (Eds.). (2009a). *Adaptation of forests and people to climate change: A global assessment report* (IUFRO world series, 224 p, Vol. 22). Vienna: International Union of Forest Research Organizations.

Seppälä, R., Buck, A., & Katila, P. (Eds.). (2009b). *Making forest lands fit for climate change: A global view of climate-change impacts on forests and people and options for adaptation*

(Policy brief, 39 p). Helsinki: Ministry of Foreign Affairs of Finland: International Union of Forest Research Organizations.
Snover, A., Whitley Binder, L., Lopez, J., Willmott, E., Kay, J., Howell, D., Simmonds, J. (2007). *Preparing for climate change: A guidebook for local, regional, and state governments* (172 p). Oakland: In association with and published by ICLEI–Local Governments for Sustainability.
Solomon, S., Quin, D., Manning, M. et al., (Eds.). (2007). *Climate change 2007: The physical science basis. Contribution of Working Group I to the fourth assessment report of the Intergovernmental Panel on Climate Change* (996 p) Cambridge: Cambridge University Press.
Solomon, A., Birdsey, R., Joyce, R., Hayes, J. (2009). *Forest Service global change research strategy overview, 2009–2019. FS-917a* (18 p). Washington, DC: U.S. Department of Agriculture, Forest Service, Research and Development. http://www.fs.fed.us/climatechange/documents/global-change-strategy.pdf
Spittlehouse, D. L. (2005). Integrating climate change adaptation into forest management. *The Forestry Chronicle, 81*, 691–695.
Stephenson, N. L., & Millar, C. I. (2012). Climate change: Wilderness' greatest challenge. *Park Science, 28*, 34–38.
Swanston, C. W., & Janowiak, M. K. (2012). *Forest adaptation resources: Climate change tools and approaches for land managers* (General Technical Report NRS-87, 121 p). Newtown Square: U.S. Department of Agriculture, Forest Service, Northern Research Station.
Swanston, C. W., Janowiak, M., Iverson, L., et al. (2011). *Ecosystem vulnerability assessment and synthesis: A report from the climate change response framework project in northern Wisconsin* (General Technical Report NRS-82, 142 p). Newtown Square: U.S. Department of Agriculture, Forest Service, Northern Research Station.
Swanston, C. W., Janowiak, M. K., & Butler, P. R. (2012). Climate change response framework overview. In C. W. Swanston & M. K. Janowiak (Eds.), *Forest adaptation resources: Climate change tools and approaches for land managers* (General Technical Report NRS-87, pp. 8–14). Newtown Square: U.S. Department of Agriculture, Forest Service, Northern Research Station.
Swinomish Indian Tribal Community [SITC]. (2010). *Swinomish climate change initiative: Climate adaptation action plan* (144 p). La Conner: Swinomish Tribal Community, Office of Planning and Community Development.
Tapash Sustainable Forest Collaborative. (2010). *The Tapash sustainable forest collaborative: Collaborative forest landscape restoration program*. http://www.tapash.org/cflra.htm. 27 Dec 2011.
The Nature Conservancy [TNC]. (2011a). *Climate Wizard*. http://www.climatewizard.org. 28 Dec 2011.
The Nature Conservancy [TNC]. (2011b). NaturePeopleFuture.org: *TNC's knowledge base for climate change adaptation*. http://www.naturepeoplefuture.org. 28 Dec 2011.
U.S. Department of Agriculture, Forest Service [USDA FS]. (2008). *Forest Service strategic framework for responding to climate change (Version 1)*. Washington, DC: U.S. Department of Agriculture, Forest Service. http://www.fs.fed.us/climatechange/documents/strategic-framework-climate-change-1-0.pdf
U.S. Department of Agriculture, Forest Service [USDA FS]. (2011a). *Climate Change Resource Center (CCRC)*. http://www.fs.fed.us/ccrc
U.S. Department of Agriculture, Forest Service [USDA FS]. (2011b). *National roadmap for responding to climate change. FS-957B* (32 p). Washington, DC: U.S. Department of Agriculture, Forest Service. http://www.fs.fed.us/climatechange/pdf/roadmapfinal.pdf
U.S. Department of Agriculture, Forest Service [USDA FS]. (2011c, August). *Navigating the performance scorecard: A guide for national forests and grasslands (Version 2)* (104 p). Washington, DC: U.S. Department of Agriculture, Forest Service. http://www.fs.fed.us/climatechange/advisor/scorecard/scorecard-guidance-08-2011.pdf. 27 Dec 2011.
U.S. Department of the Interior [DOI]. (2009). Secretarial order no. 3289. Addressing the impacts of climate change on America's water, land, and other natural and cultural resources.

U.S. Department of the Interior, Fish and Wildlife Service [DOI FWS]. (2011, March). Landscape conservation cooperatives: Shared science for a sustainable future. *Fact sheet*. http://www.fws.gov/science/shc/pdf/LCC_Fact_Sheet.pdf

U.S. Global Change Research Program [USGCRP]. (2011). *The United States national climate assessment: Uses of vulnerability assessments for the national climate assessment* (NCA Report Series, vol 9). http://downloads.globalchange.gov/nca/workshop-reports/vulnerability-assessments-workshop-report.pdf

Walters, C. (1986). *Adaptive management of renewable resources* (374 p). New York: Macmillan.

Washington State Department of Ecology. (2012). *Preparing for a changing climate: Washington state's integrated climate response strategy*. Olympia: Washington State Department of Ecology, Climate Policy Group. http://www.ecy.wa.gov/climatechange/ipa_responsestrategy.htm

Weeks, D., Malone, P., & Welling, L. (2011). Climate change scenario planning: A tool for managing parks into uncertain futures. *Park Science, 28*, 26–33.

Western Governors Association [WGA]. (2009). *Supporting the integration of climate change adaptation science in the West* (Policy Resolution 09-2, 3 p). Denver: Western Governors' Association.

Western Governors Association [WGA]. (2010). *Climate adaptation priorities for the western states: Scoping report* (20 p). Denver: Western Governors Association.

Wiens, J. A., & Bachelet, D. E. (2010). Matching the multiple scales of conservation with the multiple scales of climate change. *Conservation Biology, 24*, 51–62.