J. For. 112(5):424–433
http://dx.doi.org/10.5849/jof.13-094

silviculture

A Practical Approach for Translating Climate Change Adaptation Principles into Forest Management Actions

Maria K. Janowiak, Christopher W. Swanston, Linda M. Nagel, Leslie A. Brandt, Patricia R. Butler, Stephen D. Handler, P. Danielle Shannon, Louis R. Iverson, Stephen N. Matthews, Anantha Prasad, and Matthew P. Peters

There is an ever-growing body of literature on forest management strategies for climate change adaptation; however, few frameworks have been presented for integrating these strategies with the real-world challenges of forest management. We have developed a structured approach for translating broad adaptation concepts into specific management actions and silvicultural practices for forest adaptation, as well as an associated set of resources to assist managers in using this approach. A variety of public, private, nongovernmental, and tribal natural resource managers are using this approach to develop projects that implement a diversity of adaptation actions while also meeting manager-identified goals. We describe how managers can integrate climate change information into management planning and activities and provide examples of real-world forest management projects that identify actions to help forests adapt to changing conditions.

Keywords: climate change, adaptation, case study, forest management

As scientific information on forest vulnerability to climate change becomes increasingly available, managers are searching for ways to realistically use this information to meet the more specific needs of on-the-ground forest management, including management plans and silvicultural prescriptions (Millar et al. 2012). The amount of information available on the anticipated effects of climate change on ecosystems is growing rapidly, putting high-quality scientific information within reach of most natural resource professionals (Seppälä et al. 2009, Vose et al. 2012). Forest managers now have access to numerous websites, online tools, vulnerability assessments, and science syntheses that describe projected changes in future climate, likely effects on ecosystems, and characteristics that increase the susceptibility of forests to changing conditions.

A great deal of work has been performed to provide conceptual frameworks (e.g., Millar et al. 2007, Peterson et al. 2011), compile adaptation strategies (e.g., Ogden and Innes 2008, Heller and Zavaleta 2009), and provide tools to support management decisionmaking (e.g., Cross et al. 2012, Morelli et al. 2012). Many of these resources, however, are not being widely used by managers. A critical gap still remains between the synthesis of scientific information on climate change vulnerability and adaptation and the actual integration of these ideas into management plans and practices (Carlton et al. 2014).

Through the Climate Change Response Framework,[1] we are working to ad-

Received November 25, 2013; accepted April 1, 2014; published online May 22, 2014.

Affiliations: *Maria K. Janowiak (mjanowiak02@fs.fed.us), USDA Forest Service, Northern Institute of Applied Climate Science, Houghton, MI. Christopher W. Swanston (cswanston@fs.fed.us), USDA Forest Service, Northern Institute of Applied Climate Science. Linda M. Nagel (lmnagel@umn.edu), University of Minnesota. Leslie A. Brandt (lbrandt@fs.fed.us), USDA Forest Service, Northern Institute of Applied Climate Science. Patricia R. Butler (prbutler@mtu.edu), Michigan Technological University, Northern Institute of Applied Climate Science. Stephen D. Handler (sdhandler@fs.fed.us), USDA Forest Service, Northern Institute of Applied Climate Science. P. Danielle Shannon (dshannon@mtu.edu), Michigan Technological University, Northern Institute of Applied Climate Science. Louis R. Iverson (liverson@fs.fed.us), USDA Forest Service, Northern Research Station. Stephen N. Matthews (matthews.204@osu.edu), Ohio State University, School of Environment and Natural Resources and USDA Forest Service, Northern Research Station. Anantha Prasad (aprasad@fs.fed.us), USDA Forest Service, Northern Research Station. Matthew P. Peters (matthewppeters@fs.fed.us), USDA Forest Service, Northern Research Station.*

Acknowledgments: *The Climate Change Response Framework is supported in large part by the USDA Forest Service, Northern Research Station, Eastern Region, and Northeastern Area. We express gratitude to our numerous partners involved in adaptation demonstration projects, with special thanks to Matt Dallman, Jon Fosgitt, Jeff Grignon, Dave Mausel, Marshall Pecore, and Tony Waupochick for their involvement in the two featured adaptation demonstrations and assistance on this article. We also thank David Hollinger, Lindsey Rustad, and three anonymous reviewers for providing constructive comments on earlier drafts.*

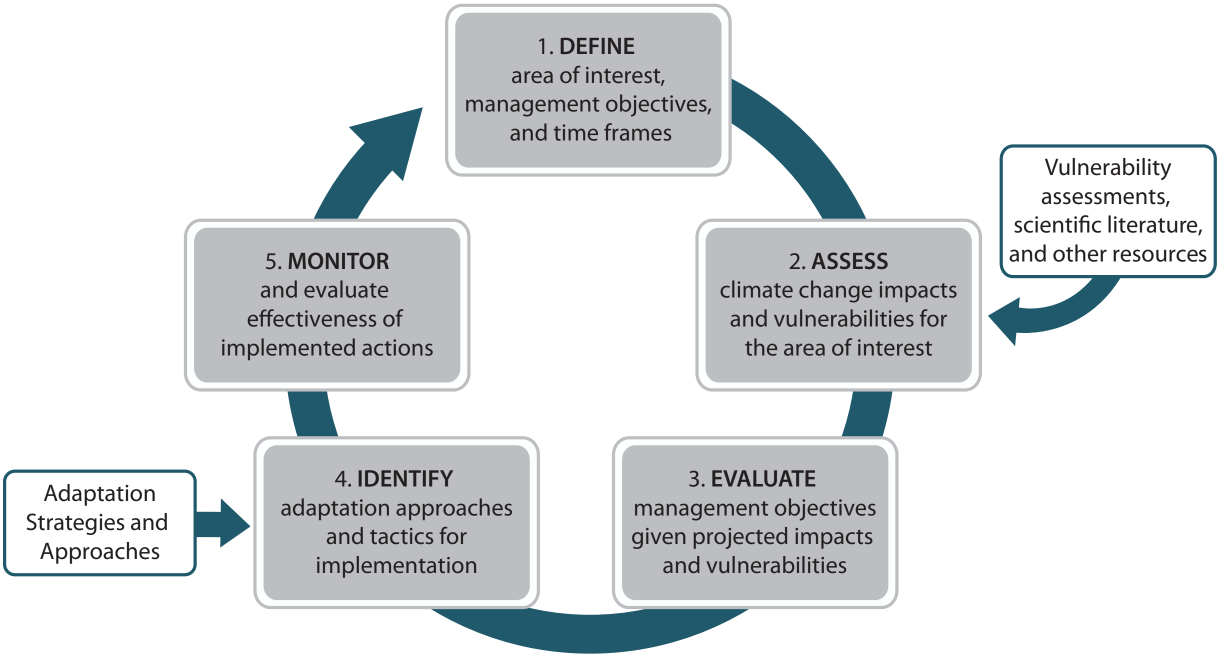

Figure 1. This five-step process can be used to incorporate climate change as a management consideration and help ecosystems adapt to the anticipated effects of climate change. Additional resources provide information and tools that support the process. (From Swanston and Janowiak 2012.)

dress this issue and translate the largely broad-scale and conceptual information into tangible, actionable projects that can be used by forest managers and other natural resource professionals to advance their on-the-ground work. Beginning as a pilot program in northern Wisconsin, this highly collaborative effort expanded to several ecoregional projects across the midwest and northeast United States. It builds off of two fundamental ideas. First, because climate change inherently adds complexity and uncertainty to the process of making forest management decisions, there is no single "answer" for how managers should address climate change in management. Additionally, differences in existing management goals and values will naturally result in a diversity of adaptation actions. Rather than providing recommendations or prescriptive actions, we designed a flexible approach that accommodates a diversity of management goals, forest ecosystems, ownership types, and spatial scales (Swanston and Janowiak 2012).

Through this approach, managers begin with the current management goals and objectives for a particular forest management project (Figure 1). Climate change is then incorporated as an additional "filter" through which to consider potential management responses and outcomes. Once adaptation actions are identified to help achieve management goals, monitoring is used to evaluate whether the goals and objectives were achieved, and assess the role of the selected adaptation actions in meeting the desired outcome. A set of forest adaptation resources, described below, assist managers in working through this process.

One of the strengths of this approach is the built-in flexibility that accounts for different future conditions. Given the need to consider incomplete information and to "learn by doing," adaptive management principles are well-suited for incorporating climate change considerations into management (Stankey et al. 2005, Lawler et al. 2010, Millar et al. 2012). Several aspects of adaptive management are evident in working through this approach, including explicit acknowledgment and consideration of uncertainty, iterative learning to improve understanding and reduce uncertainty, integration of monitoring, and a focus on continued improvement to achieve desired outcomes (Williams et al. 2007, Larson et al. 2013). In particular, the intentional use of monitoring to evaluate the effectiveness of adaptation actions helps to inform future management decisions. Further, because the individual steps mirror other processes used

Management and Policy Implications

Land management agencies and organizations are under increasing pressure to integrate climate change considerations into planning and implementation activities. The Climate Change Response Framework engages natural resource managers in working collaboratively across multiple spatial scales, provides usable information and resources regarding climate change, and facilitates application of this information through on-the-ground management. Adaptation resources increase the ability of forest management plans, projects, and prescriptions to outline actions to help forests adapt to changing conditions, while simultaneously working to achieve the management goals associated with a particular piece of land. The "abstractness" of climate change adaptation as a management issue is a major barrier to its application because it is difficult to transfer broad concepts of resistance, resilience, and transition into management tactics; adaptation demonstration projects developed through this framework approach provide much-needed examples of how adaptation "looks and feels" in real-world situations and advances the dialogue surrounding climate change response.

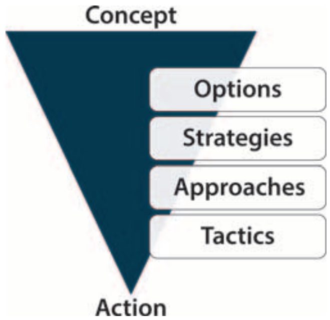

Figure 2. Adaptation responses can be translated from broad, conceptual options into specific, actionable tactics.

during management planning, ideas generated through the consideration of climate change can be easily incorporated into management plans, silvicultural prescriptions, or other plans.

This approach has been applied in more than 40 forest management projects across numerous ownership types, ranging in size from stand-level silvicultural prescriptions to management plans covering thousands of acres. Below, we describe how this approach is used to integrate climate change considerations into forest management activities and provide examples of its application.

Forest Adaptation Resources

We developed multiple resources to assist managers in using this approach (Swanston and Janowiak 2012). Vulnerability assessments summarize scientific information on climate change impacts, which managers interpret in the context of a particular location and set of management goals (Figure 1). A menu of adaptation strategies and approaches outlines potential adaptation actions that managers can choose from based on their needs serves as a starting point for prescribing specific actions. An adaptation workbook provides step-by-step instructions to walk managers through the entire process and document ideas.

Adaptation Strategies and Approaches

One core resource that is provided as part of this flexible approach is a synthesis of strategies and approaches for adapting forests to climate change, derived from a wide range of reports and peer-reviewed publications on climate change adaptation. The strategies and approaches are part of a continuum of adaptation actions (Figure 2). At the highest level are the broad and largely conceptual options of resistance (forestall change), resilience (enhance resilience of ecosystems to change), and response (transition ecosystems into alignment with anticipated future conditions) (Millar et al. 2007). Adaptation strategies and approaches provide intermediate "stepping stones" that enable managers to translate broad concepts into targeted and prescriptive tactics for implementing adaptation (Janowiak et al. 2011). Ten strategies and 39 more specific approaches were synthesized from dozens of scientific papers that discussed adaptation actions at a variety of scales and locations and are presented as a "menu" of adaptation actions (Table 1). Initially we developed this list with a focus on forest ecosystems in northern Wisconsin, but they have proven to be broadly applicable to a variety of terrestrial ecosystem types in the United States. By stating an intention to promote resistance, resilience, or response and explicitly linking the strategies and approaches to on-the-ground tactics, managers are better able to specify how they will meet management goals through adaptation. Further, this enables future generations to judge success.

Table 1. List of adaptation strategies and approaches.

Strategy 1: Sustain fundamental ecological functions.
1.1—Maintain or restore soil quality and nutrient cycling.
1.2—Maintain or restore hydrology.
1.3—Maintain or restore riparian areas.
Strategy 2: Reduce the impact of existing biological stressors.
2.1—Maintain or improve the ability of forests to resist pests and pathogens.
2.2—Prevent the introduction and establishment of invasive plant species and remove existing invasives.
2.3—Manage herbivory to protect or promote regeneration.
Strategy 3: Protect forests from severe fire and wind disturbance.
3.1—Alter forest structure or composition to reduce risk or severity of fire.
3.2—Establish fuelbreaks to slow the spread of catastrophic fire.
3.3—Alter forest structure to reduce severity or extent of wind and ice damage.
Strategy 4: Maintain or create refugia.
4.1—Prioritize and protect existing populations on unique sites.
4.2—Prioritize and protect sensitive or at-risk species or communities.
4.3—Establish artificial reserves for at-risk and displaced species.
Strategy 5: Maintain and enhance species and structural diversity.
5.1—Promote diverse age classes.
5.2—Maintain and restore diversity of native tree species.
5.3—Retain biological legacies.
5.4—Restore fire to fire-adapted ecosystems.
5.5—Establish reserves to protect ecosystem diversity.
Strategy 6: Increase ecosystem redundancy across the landscape.
6.1—Manage habitats over a range of sites and conditions.
6.2—Expand the boundaries of reserves to increase diversity.
Strategy 7: Promote landscape connectivity.
7.1—Use landscape-scale planning and partnerships to reduce fragmentation and enhance connectivity.
7.2—Establish and expand reserves and reserve networks to link habitats and protect key communities.
7.3—Maintain and create habitat corridors through reforestation or restoration.
Strategy 8: Enhance genetic diversity.
8.1—Use seeds, germplasm, and other genetic material from across a greater geographic range.
8.2—Favor existing genotypes that are better adapted to future conditions.
8.3—Increase diversity of nursery stock to provide those species or genotypes likely to succeed.
Strategy 9: Facilitate community adjustments through species transitions.
9.1— Anticipate and respond to species decline.
9.2— Favor or restore native species that are expected to be better adapted to future conditions.
9.3—Manage for species and genotypes with wide moisture and temperature tolerances.
9.4—Emphasize drought- and heat-tolerant species and populations.
9.5—Guide species composition at early stages of stand development.
9.6—Protect future-adapted regeneration from herbivory.
9.7—Establish or encourage new mixes of native species.
9.8—Identify and move species to sites that are likely to provide future habitat.
Strategy 10: Plan for and respond to disturbance.
10.1—Prepare for more frequent and more severe disturbances.
10.2—Prepare to realign significantly altered ecosystems to meet expected future environmental conditions.
10.3—Promptly revegetate sites after disturbance.
10.4—Allow for areas of natural regeneration after disturbance.
10.5—Maintain seed or nursery stock of desired species for use after severe disturbance.
10.6—Remove or prevent establishment of invasives and other competitors after disturbance.

See Butler et al. (2012) for complete descriptions.

Adaptation Workbook

We also developed an adaptation workbook to implement the five-step process described above (Figure 1). It provides a structured approach for managers to work through this process and draws on region-specific information such as climate change

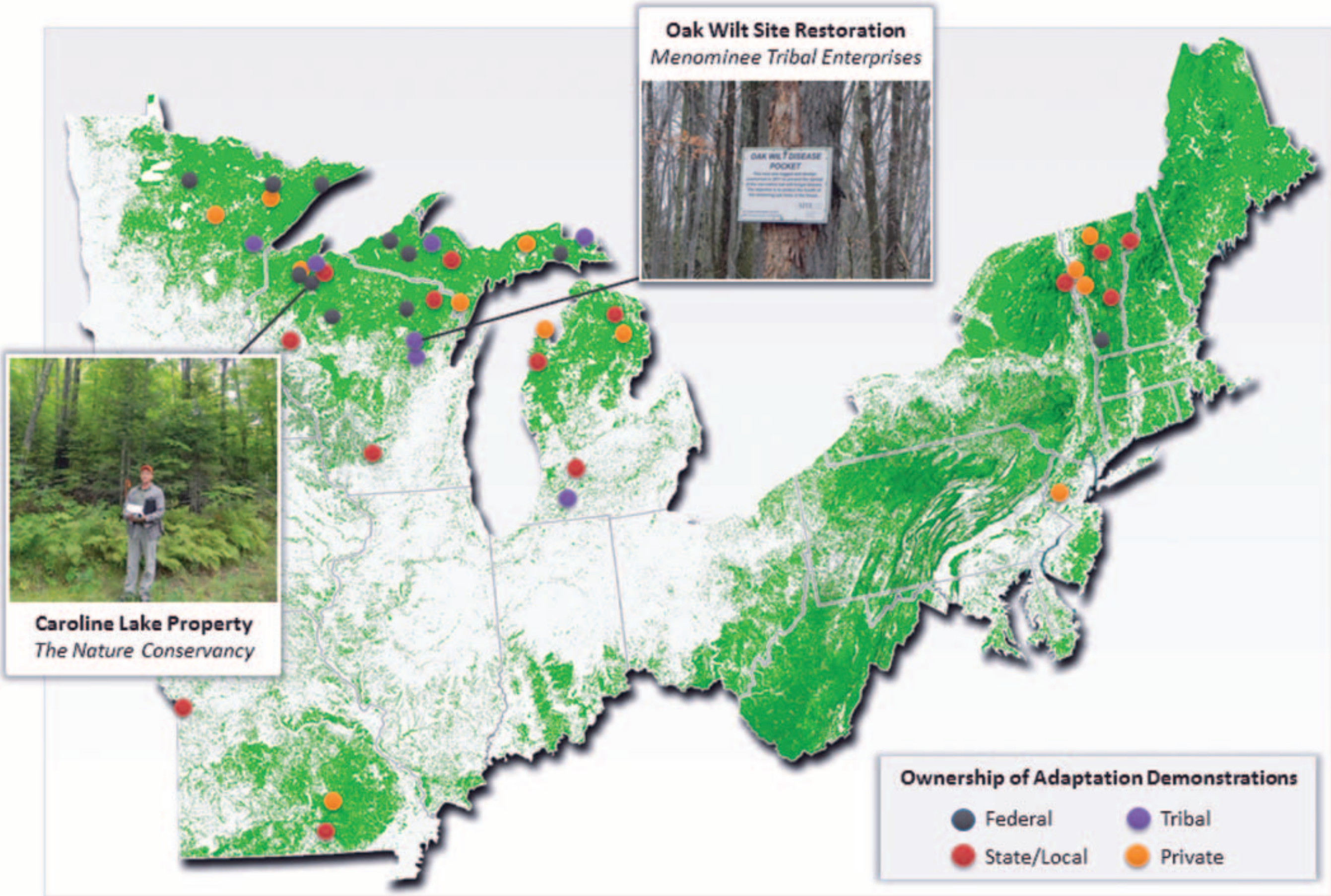

Figure 3. Location of adaptation demonstration projects that have been developed through the Climate Change Response Framework in the midwest and northeast United States, featuring the two projects detailed in the text. (For details on other projects, see Endnote 2.)

vulnerability assessments. It is designed to incorporate climate change considerations into resource management at a variety of spatial scales (single stands to large ownerships) and many levels of decisionmaking (e.g., planning and implementation). It is not intended to provide specific solutions but rather draws on the expertise of natural resource professionals and complements already existing processes for developing plans and projects. It provides step-by-step instructions for land managers to translate the adaptation strategies and approaches, described above, into on-the-ground management tactics intended to help forest ecosystems adapt to climate change. Finally, it helps managers consider how a suite of forest management actions can be implemented over long time periods to maintain desired ecosystem functions and benefits across a range of plausible future climates.

Application of the Forest Adaptation Resources

Working with a variety of public, private, nongovernmental, and tribal land managers, we have developed numerous adaptation demonstration projects,[2] which serve as real-world examples of the integration of climate change information into forest management. More than 40 of these "case studies" have been developed using the resources described above and reflecting diverse forest ownerships, management objectives, and spatial scales. In the adaptation demonstrations developed thus far, an individual or small group of land owners and managers use the adaptation workbook in a facilitated discussion or training session, which is led by a specialist with expertise in both climate change and forest management. In other instances, managers use the adaptation workbook independently to consider climate change in a silvicultural prescription or management plan. For large projects, such as vegetation management projects on federally managed lands that can span tens of thousands of acres, interdisciplinary teams of 5–15 members may be involved in the discussion, and it may take multiple days to consider and document the potential effects of climate change and discuss possible responses for adaptation. Less time is generally needed for smaller properties and parcels, and the amount of time will vary depending on the complexity of the project area and the number of people involved. For example, for the 400-acre Lincoln Community Forest (Bayfield County, Wisconsin), a group of local natural resource professionals and residents participated in a facilitated discussion of the adaptation workbook lasting about 3 hours. Afterward, the forest manager used the ideas generated from the discussion, input from the organization owning the lands, and his or her expertise to complete the adaptation workbook and integrate that information into a forest management plan for the property. Here, we summarize two adaptation demonstration projects to show different applications of climate change adaptation in forest management (Figure 3).

Caroline Lake Property

The Nature Conservancy (TNC) owns and manages >1,000 acres of forest on the Caroline Lake Property in northern Wisconsin (Ashland County, Wisconsin) (Figure 3). The property was acquired from industrial ownership in 1997 and has since been maintained as a working forest to demonstrate sustainable forestry practices. Natural resource professionals from TNC and the Wisconsin Department of Natural Resources used the adaptation workbook with facilitation to consider climate change effects on the property as part of updating the property's forest management plan. A consulting forester worked with TNC staff to translate the proposed adaptation actions into stand-level recommendations for the new plan. The adaptation workbook steps for this site are detailed below.

1. Define Area of Interest, Management Goals and Objectives, and Time Frames. Since 1997, the Caroline Lake Property has been actively managed with the intent of restoring characteristics associated with pre-European settlement forests. Much of the property contains upland northern hardwood forest, with numerous areas of lowland hardwood and conifer forest. Before considering the potential effects of climate change on the property, TNC management generally sought to encourage mid- to late-successional forest characteristics, emulate natural disturbance dynamics, and increase underrepresented species and age diversity. Transitional forests adjacent to lakes and lowland forests had been designated as no-harvest reserve areas.

2. Assess Climate Change Impacts and Vulnerabilities for the Area of Interest. A vulnerability assessment for forest ecosystems in northern Wisconsin (Swanston et al. 2011) was used to identify potential climate change effects across the region. The managers combined this broad-scale information with their knowledge of the local landscape to identify attributes of the property that they believed would increase or decrease risks from climate change. For example, many common tree species are projected to have reduced habitat suitability or productivity by the end of the century across northern Wisconsin (Swanston et al. 2011, Janowiak et al. 2014). In particular, black spruce (*Picea mariana*), balsam fir (*Abies balsamea*), quaking aspen (*Populus tremuloides*), and other boreal species are at the southern extent of their range in the region. These species are projected to decline substantially over the next century under multiple climate scenarios. Other important species, such as sugar maple (*Acer saccharum*), eastern hemlock (*Tsuga canadensis*), yellow birch (*Betula alleghaniensis*), and eastern white pine (*Pinus strobus*), are also projected to decrease due to climate change; however, the projected decreases are less than those for boreal species and generally only under climate scenarios that project greater levels of climate warming (Swanston et al. 2011, Janowiak et al. 2014). Boreal and northern tree species are abundant on the Caroline Lake Property, putting the forest at risk. At the same time, the property has a notably high diversity of tree species compared with other tracts in the vicinity, which may reduce certain risks if one or a few tree species undergo especially large declines.

A number of other potential effects on the property from climate change were also considered. These included direct effects on forests from warmer temperatures, altered precipitation, and extreme weather events, as well as indirect impacts related to interactions with forest pests and diseases and other stressors (Swanston et al. 2011, Janowiak et al. 2014). Projected changes in precipitation and associated hydrology were identified as having the potential to greatly affect forests, but these projections were also the most uncertain. Projections of summer precipitation are highly variable for the region, but the combination of earlier spring snow melts and warmer temperatures without a compensatory increase in summer precipitation generally suggests drier summer conditions and altered hydrology. Lowland conifer forests, which contain a disproportionate amount of tree species that are expected to decline due to climate change, may be at particular risk if hydrology is disrupted.

3. Evaluate Management Objectives Given Projected Impacts and Vulnerabilities. In this step, managers explored the opportunities and challenges to meeting the property- and stand-level management goals and objectives under changing conditions. Many of the challenges were based on the vulnerabilities identified in the previous step, such as the challenge of promoting eastern hemlock and yellow birch in the upland hardwoods stands when some model results suggest that these species are at increased risk of declining by the end of the century. At the same time, the species diversity present in these stands provided many opportunities to maintain a sufficiently healthy forest and work toward goals related to increasing underrepresented species and increasing characteristics associated with older forests. Even the increased frequency of disturbance from extreme weather events was viewed as a potential opportunity (as long as the extent was not too great) because of the interest in incorporating natural disturbance patterns into management. Although the managers did not feel that the management trajectory needed to change dramatically as a result of considering climate change, they recognized that some of the goals associated with restoring pre-European settlement tree species composition would become more challenging and that considering a broader suite of tree species could increase the likelihood of achieving other management goals.

4. Identify Adaptation Approaches and Tactics for Implementation. Within this context, a number of potential adaptation actions were identified with the overarching intent to maintain the resilience of the forest to changing conditions (Table 2). In the northern hardwood forest, actions to maintain and enhance tree species diversity were prescribed to reduce the risk from climate change-related declines in the dominant species. This included the use of group selection and shelterwood harvests to enhance natural regeneration of midtolerant species. Several of these species, including northern red oak (*Quercus rubra*) and black cherry (*Prunus serotina*), are currently present on the property in relatively low amounts and are projected to fare better under climate change relative to other species that are currently present. Eastern white pine was also identified as a desirable species. Although it is projected to decrease under some climate scenarios, the species is at a lower risk of decline than other native conifer species.

The managers generally viewed the proposed actions as slight adjustments to rather than a significant departure from the current management trajectory. In addition, several "contingency plans" were discussed for responding to disturbances or other unforeseen events. For example, lowland hardwood forests were identified as at risk from altered hydrologic regimes and reduced late growing season soil moisture from climate change, introduction of the emerald ash borer (*Agrilus planipennis*), or a combination of these threats. Although no active management is currently planned in these stands, swamp white oak (*Quercus bicolor*) and bur oak (*Quercus macrocarpa*) were identified as two potential species that could be planted

Table 2. Selected proposed adaptation actions identified for the Caroline Lake Property in northern Wisconsin.

Stand	Current management activity	Proposed adaptation actions
Northern hardwoods (643 acres)	Use single-tree or group selection methods to maintain species composition/diversity and increase structural diversity	Use single-tree selection with additional use of targeted gaps and seed trees to maintain or enhance species diversity (e.g., midtolerant species) and age-class diversity. Use large group selection or shelterwood harvests to increase northern red oak component in areas where natural regeneration is present. Where opportunities exist, promote white pine, black cherry, yellow birch, and other desirable species that have lower risk declining as a result of climate change. Look for opportunities to reserve high-quality pockets of hemlock on less vulnerable sites to serve as refugia for that species.
Lowland conifer (259 acres)	No harvest reserve area	Maintain as no harvest reserve area. Increase monitoring to detect hydrological changes in peatland systems; revisit planned management if changes are observed.
Lowland hardwoods (78 acres)	No harvest reserve area	Maintain as no harvest reserve area. Monitor stocking and natural regeneration of desired species; if inadequate, consider experimental plantings of swamp white oak or bur oak as species that are not currently present in the area but may do well in the future.
Shoreline buffer (<5 acres)	No harvest reserve area	Where opportunities exist, promote white pine or other species to provide long-lived conifer component and shading along lake shorelines.
Upland conifer (<5 acres)	Promote long-lived conifers	Promote long-lived conifers, with additional emphasis on species that are at lower risk of decline under climate change, such as white pine.

The current management activities reflect the 2005 forest management plan and did not take the effects of climate change into account. The proposed adaptation actions were identified as part of the adaptation workbook process and will be integrated into a new, updated forest management plan.

in lowland hardwood forests to maintain forest cover if intervention was deemed necessary. These species are not currently present on the property but can be found in localized areas in northern Wisconsin, which would represent a small degree of assisted migration.

5. Monitor and Evaluate Effectiveness of Implemented Actions. Managers from TNC and the consultancy responsible for the property management identified forest inventory data as an integral component of monitoring the effectiveness of adaptation actions over time. Permanent forest inventory plots were established in random locations across the property, and a comprehensive inventory was performed to document stand characteristics and ecological attributes. The robust inventory provided a useful baseline for prescribing management activities for adaptation. For example, data on tree species abundance were used to calculate tree species richness and diversity evenness and provided an indication of the relative risk associated with the loss of different tree species. In addition, the presence of advanced regeneration of northern red oak and black cherry (tree species that may be better adapted to future conditions) was evident in the inventory data. In the future, inventories repeated at approximately 10-year intervals will be used to evaluate whether the selected management activities increase the abundance of these species in the understory and eventually the overstory.

Current Status. A forest management plan, which will integrate the ideas that were generated by managers while using the adaptation workbook, is in development for the Caroline Lake Property. The proposed adaptation actions will be evaluated further, refined, and put into the plan. In addition, a complete set of monitoring indicators based on common forest inventory data is in development and will be included in the plan so that future inventory data can be used to evaluate the effectiveness of the adaptation actions over time.

Menominee Indian Reservation

Menominee Tribal Enterprises (MTE) manages 220,000 acres of forestland and is the forest products business arm of the Menominee Indian Tribe of Wisconsin (Menominee County, Wisconsin) (Figure 3). Management focuses on maintaining diverse species and habitats for cultural and environmental values, while also emphasizing the sustainable production of forest products. These lands are often regarded as a model of forest stewardship due to a long history of sustainable and innovative forest management. MTE is concerned with many forest health issues, all of which can reduce forest productivity and function. Foresters from MTE used the adaptation workbook and relevant climate change information to inform the management response to oak wilt in dry-mesic mixed hardwood stands.

1. Define Area of Interest, Management Goals and Objectives, and Time Frames. On the Menominee Forest, approximately 350 pockets of forest affected by oak wilt were found and treated between 2008 and 2013. Oak wilt is a vector-transmitted disease caused by a nonnative fungal pathogen (*Ceratocystis fagacearum*), which can kill trees by clogging xylem vessels. It is generally spread by sap-feeding beetles or through root grafts, and red oaks (section *Lobatae*) are generally more susceptible to the disease than white oaks (section *Quercus*) in North America (Rexrode and Brown 1983, Koch et al. 2010, Wisconsin Department of Natural Resources 2013). The affected oak wilt pockets are generally 1/2–1 acre in size, although some treatment areas are larger. Treatment typically involves salvaging any affected or potentially affected oak trees and adjacent trees and then removing stumps from the ground to avoid transmission of the fungus through roots (Figure 4). After treatment, the oak wilt sites are heavily disturbed, with few or no trees left on site. In the recent past, northern red oak, white pine, and other species have naturally regenerated on these sites. Foresters from MTE are interested in actively restoring the sites to productive forest to provide multiple benefits to the Tribe, as well as enhancing their ability to adapt to future conditions.

2. Assess Climate Change Impacts and Vulnerabilities for the Area of Interest. Broadly speaking, projected climate change impacts are similar across northern Wisconsin, and many of the issues that were identified on the TNC Caroline Lake Property also apply to the Menominee oak wilt sites (Swanston et al. 2011). Managers from MTE identified many of the same potential vulnerabilities on these sites,

Figure 4. Oak wilt sites on the Menominee forest. Top: oak wilt sites after trees have been harvested and oak stumps pulled from the ground. Bottom left: adaptation demonstration site after site preparation, August 2013. Bottom right: bur oak seedlings for planting. (Images courtesy Jeff Grignon, Dave Mausel, and Tony Waupochick, Menominee Tribal Enterprises.)

such as the loss of several dominant and desired tree species. However, the oak wilt sites are generally found in dry-mesic forests that form the transition between hemlock-hardwood forest to the northwest and drier oak forest and barrens to the southeast on the Menominee Forest. Given this transitional location, forests affected by oak wilt often have numerous species capable of thriving across a variety of soil types and site conditions. Further, several tree species commonly associated with ecosystems farther south are present on the Menominee Reservation because of its location at the southern extent of the Laurentian Mixed Forest Province.

3. Evaluate Management Objectives Given Projected Impacts and Vulnerabilities. Management on the Menominee Forest emphasizes a sustainable production of forest products to provide a suite of ecological, cultural, and economic benefits to the members of the Tribe. Given this goal, oak wilt presents a substantial challenge because it reduces the ability of achieving these diverse goals. Oak wilt site treatment, which is intended to reduce the spread and impact of the disease on the forest and capture the timber value of affected trees, results in heavily disturbed sites that would benefit from restoration. Climate change is then viewed as an opportunity to plant and foster different tree and understory plant assemblages that may be better able to respond to altered stressors in the future.

4. Identify Adaptation Approaches and Tactics for Implementation. Several potential actions were suggested and discussed. One option identified, which has been practiced by other land management organizations in the region, was to allow the sites to naturally regenerate because the soil disturbance would allow for red oak and many light-seeded species to regenerate on the site over time. This option was less preferable in some situations because of the intention to maintain higher levels of forest productivity, as well as concerns over the potential for nonnative invasives and other undesirable plant and tree species to become established and outcompete more desirable species.

Foresters from MTE decided to use natural regeneration across most sites and to restore some sites through supplemental planting of a wide variety of tree and other plant species. Managers used a combination of scientific information, traditional ecological knowledge, and manager expertise to select numerous tree and plant species. The majority of tree species selected for planting are expected to fare better under climate change and to have lower susceptibility to oak wilt, and planting multiple species was viewed as a way to increase the probability of success. Importantly, the species selected would also help to achieve a number of other forestwide goals, such as fostering diverse habitats and benefiting the community by providing high-quality sawtimber for the MTE-operated mill. In addition, the oak wilt sites closest to highly traveled roads were selected for adaptation practices to provide educational opportunities on forest pest management and climate change adaptation for community members. Lastly, the managers also decided to plant herbaceous and grass species that are culturally important to members of the Menominee community. Because data on the potential distribution of these nontree species under climate change

Table 3. Potential changes in suitable habitat for 73 tree species across northern Wisconsin.

Common name	PCM B1	HAD A1FI	Common name	PCM B1	HAD A1FI
Declines under both scenarios			Mixed results		
Balsam fir	Large decrease	Large decrease	Balsam poplar	Large decrease	Increase
Black ash	Decrease	Decrease	Bigtooth aspen	No change	Large decrease
Black spruce	Large decrease	Large decrease	Butternut	Large increase	Extirpated
Eastern hemlock	Decrease	Large decrease	Chokecherry	No change	Large decrease
Jack pine	Decrease	Decrease	Eastern hophornbeam	No change	Increase
Mountain maple	Extirpated	Extirpated	Eastern white pine	No change	Large decrease
Northern white-cedar	Large decrease	Large decrease	Green ash	Decrease	Increase
Paper birch	Large decrease	Large decrease	Northern red oak	Increase	No change
Quaking aspen	Large decrease	Large decrease	Red maple	No change	Decrease
Rock elm	Decrease	Decrease	Red pine	No change	Decrease
Sugar maple	Decrease	Large decrease	New suitable habitat		
Tamarack	Decrease	Decrease	Black hickory		New entry
White spruce	Decrease	Large decrease	Black locust	New entry	New entry
Yellow birch	Large decrease	Large decrease	Blackgum		New entry
No change under both scenarios			Blackjack oak		New entry
American basswood	No change	No change	Chestnut oak		New entry
Northern pin oak	No change	No change	Chinkapin oak		New entry
Increases under both scenarios			Common persimmon		New entry
American beech	Large increase	Large increase	Eastern redbud		New entry
American elm	Increase	Large increase	Flowering dogwood	New entry	New entry
Bitternut hickory	Large increase	Large increase	Honey locust	New entry	New entry
Black cherry	Large increase	Increase	Mockernut hickory	New entry	New entry
Black oak	Large increase	Large increase	Northern catalpa		New entry
Black walnut	Large increase	Large increase	Ohio buckeye	New entry	New entry
Black willow	Large increase	Large increase	Peachleaf willow		New entry
Boxelder	Large increase	Large increase	Pecan		New entry
Bur oak	Increase	Large increase	Pignut hickory	New entry	New entry
Eastern cottonwood	Large increase	Large increase	Pin oak	New entry	New entry
Eastern red cedar	Large increase	Large increase	Post oak		New entry
Hackberry	Large increase	Large increase	Red mulberry	New entry	New entry
Osage orange	Large increase	Large increase	River birch	New entry	New entry
Shagbark hickory	Large increase	Large increase	Sassafras	New entry	New entry
Silver maple	Large increase	Large increase	Scarlet oak	New entry	New entry
Slippery elm	Large increase	Large increase	Shingle oak		New entry
Swamp white oak	Increase	Large increase	Sugarberry		New entry
White oak	Large increase	Large increase	Sycamore	New entry	New entry
			Wild plum		New entry
			Yellow poplar	New entry	New entry

Projected changes in future suitable habitat were derived using the Climate Change Tree Atlas (Landscape Change Research Group 2014) and are summarized from Swanston et al. (2011). Species are grouped according to change classes based on the projected change in importance value projected for the end of century (2070–2100) under two climate scenarios. No change represents a <20% change in future suitable habitat. Large decreases refer to >40% decreases in suitable habitat, and large increases indicate more than a doubling (200% increase) in suitable habitat at the end of the century. See Iverson et al. (2008) and Landscape Change Research Group (2014) for a complete description of the Climate Change Tree Atlas and methods.

are not available, traditional ecological knowledge and manager expertise were used for species selection.

Modeled results from the Climate Change Tree Atlas[3] provided additional information for the selection of suitable tree species. The Tree Atlas is a species distribution model that provides information on the potential suitable habitat of tree species under a range of climate change scenarios (Iverson et al. 2008, Landscape Change Research Group 2014). Projections of future suitable habitats in northern Wisconsin, as well as other climate change information, informed species selection (Table 3) (Swanston et al. 2011). Additional Tree Atlas projections were also produced for an area approximately 30 miles around the Menominee Forest to provide more local information (Supplemental Table S1).[S] Across northern Wisconsin and locally near the Menominee Forest, habitats suitable for northern red oak, northern pin oak (*Quercus ellipsoidalis*), and black oak (*Quercus velutina*) were not projected to decrease with climate change, but these species are susceptible to oak wilt and their widespread planting could increase the future risk of mortality. Bur oak and white oak (*Quercus alba*) currently have low abundance in the area and were identified as the primary tree species to be planted at sites receiving supplemental plantings.

Several other tree species were identified for potential planting at low levels. Black cherry, black oak, and American elm (*Ulmus americana*) are current associate species that are also expected to see increases in habitat under climate change. For American elm, a seed source resistant to Dutch Elm Disease (*Ophiostoma ulmi*) was identified to help increase the species' likelihood of success. Further, several species that are not currently present in the area but are modeled to have suitable habitat appearing within this century were selected for potential planting, including black walnut (*Juglans nigra*), shagbark hickory (*Carya ovata*), and chinkapin oak (*Quercus muehlenbergii*), although the managers recognize that thousand cankers disease may be an issue for black walnut in the future. All of these supplemental species are intended to help restore forest to the sites, enhance diversity, and begin testing options that will slowly transition ecosystems to communities

[S] Supplementary data are available with this article at http://dx.doi.org/10.5849/jof.13-094.

Figure 5. Discussion of site preparation and adaptation activities planned for the oak wilt restoration sites on the Menominee Forest.

that contain a greater proportion of species adapted to future conditions.

5. Monitor and Evaluate Effectiveness of Implemented Actions. Monitoring metrics were identified to evaluate the effectiveness of the adaptation actions over time. Many of these are focused on tracking the success of the plantings. In addition, monitoring of forest insects, diseases, and invasive species will inform future management. As the activities are implemented, the associated costs and labor are also being recorded to inform future restoration activities.

Current status. MTE foresters identified 10 oak wilt sites to serve as adaptation demonstration areas. These sites tend to be large or in areas of high visibility, making them good candidates for restoration and education (Figure 5). Sites were prepared for planting using a roller chopper in summer 2013. Some trees were planted during summer 2013 using readily available white oak and bur oak seedlings grown from locally collected seed. A larger array of tree, grass, and herb species are being sourced for planting during 2014. These species are being selected based on the considerations described above and on the availability of seed and seedlings from various genetic sources. The planted trees are expected to be sourced from seed gathered locally on the Menominee Forest or from one seed zone south.

Conclusion

Climate change adaptation is a rapidly growing field and will continue to grow as more of the management community responds, as modeling and projections increase in reliability and decrease in uncertainty, and as climate change-related impacts increase. Although adaptation inherently spans the boundary between the research and management communities, the current conversation within the forestry community is still largely centered on understanding the potential impacts of climate change on forests. In our opinion, this limited view is inadequate, as the complexity and increasing urgency of the issue as well as the need for place-based decisions require active engagement from forest managers and other natural resource professionals.

The approach we have developed advances the discussion of climate change among forest practitioners and emphasizes their role in understanding how climate change will affect the specific places they manage and what actions can begin to help forests adapt. By creating tangible examples of what forest adaptation looks like from a manager's perspective, we hope to demystify "the climate change issue" and bring it into the mainstream as another consideration in forest management. This framework is an example of an ongoing and sustainable research-management partnership that is helping resource managers successfully incorporate climate change adaptation into their on-the-ground management activities.

Endnotes

1. For more details on the Climate Change Response Framework, see www.forestadaptation.org.
2. For more details on adaptation demonstration projects, see www.forestadaptation.org/demonstration-projects.
3. For more details on the Climate Change Tree Atlas, see www.nrs.fs.fed.us/atlas/tree/.

Literature Cited

Butler, P., C. Swanston, M. Janowiak, L. Parker, M. St. Pierre, and L. Brandt. 2012. Adaptation strategies and approaches. P. 15–34 in *Forest adaptation resources: Climate change tools and approaches for land managers,* Swanston, C.W., and M.K. Janowiak (eds.). USDA For. Serv., Gen. Tech. Rep. NRS-87, Northern Research Station, Newtown Square, PA. Available online at www.nrs.fs.fed.us/pubs/42179; last accessed Mar. 14, 2014.

Carlton, J.S., J.R. Angel, S. Fei, M. Huber, T.M. Koontz, B.J. MacGowan, N.D. Mullendore, N. Babin, and L.S. Prokopy. 2014. State service foresters' attitudes toward using climate and weather information when advising forest landowners. *J. For.* 112(1): 9–14.

Cross, M.S., E.S. Zavaleta, D. Bachelet, M.L. Brooks, C.A.F. Enquist, E. Fleishman, L.J. Graumlich, et al. 2012. The adaptation for conservation targets (ACT) framework: A tool for incorporating climate change into natural resource management. *Environ. Manage.* 50(3):341–351.

Heller, N.E., and E.S. Zavaleta. 2009. Biodiversity management in the face of climate change: A review of 22 years of recommendations. *Biol. Conserv.* 142(1):14–32.

Iverson, L.R., A.M. Prasad, S.N. Matthews, and M. Peters. 2008. Estimating potential habitat for 134 eastern US tree species under six climate scenarios. *For. Ecol. Manage.* 254(3):390–406.

Janowiak, M.K., L. Iverson, D.J. Mladenoff, E. Peters, K.R. Wythers, W. Xi, L.A. Brandt, et al. 2014. *Forest ecosystem vulnerability assessment and synthesis for northern Wisconsin and western Upper Michigan: A report from the Northwoods Climate Change Response Framework*. USDA For. Serv., Gen. Tech. Rep., Northern Research Station, Newtown Square, PA. In press.

Janowiak, M.K., C.W. Swanston, L.M. Nagel, C.R. Webster, B.J. Palik, M.J. Twery, J.B. Bradford, L.R. Parker, A.T. Hille, and S.M. Johnson. 2011. *Silvicultural decision-making in an uncertain climate future: A workshop-based exploration of considerations, strategies, and approaches*. USDA For. Serv., Gen.

Tech. Rep. NRS-81, Northern Research Station, Newtown Square, PA. 14 p.

Koch, K.A., G.L. Quiram, and R.C. Venette. 2010. A review of oak wilt management: A summary of treatment options and their efficacy. *Urban For. Urban Green.* 9:1.

Landscape Change Research Group. 2014. *Climate change atlas*. USDA For. Serv., Northern Research Station, Delaware, OH. Available online at www.fs.fed.us/nrs/atlas/; last accessed Mar. 14, 2014.

Larson, A.J., R.T. Belote, M.A. Williamson, and G.H. Aplet. 2013. Making monitoring count: Project design for active adaptive management. *J. For.* 111(5):348–356.

Lawler, J.J., T.H. Tear, C. Pyke, M.R. Shaw, P. Gonzalez, P. Kareiva, L. Hansen, et al. 2010. Resource management in a changing and uncertain climate. *Front. Ecol. Environ.* 8(1):35–43.

Millar, C.I., K.E. Skog, D.C. McKinley, R.A. Birdsey, C. Swanston, S.J. Hines, C.W. Woodall, E.D. Reinhart, D.L. Peterson, and J.M. Vose. 2012. Adaptation and Mitigation. P. 7–95 in *Effects of climatic variability and change on forest ecosystems: A comprehensive science synthesis for the US forest sector*, Vose, J.M., D.L. Peterson, and T. Patel-Weynand (eds.). USDA For. Serv., Gen. Tech. Rep. PNW-GTR-870, Pacific Northwest Research Station, Portland, OR.

Millar, C.I., N.L. Stephenson, and S.L. Stephens. 2007. Climate change and forests of the future: Managing in the face of uncertainty. *Ecol. Appl.* 17(8):2145–2151.

Morelli, T.L., S. Yeh, N. Smith, M.B. Hennessey, and C.I. Millar. 2012. *Climate project screening tool: An aid for climate change adaptation*. USDA For. Serv., Res. Pap. PSW-RP-263, Pacific Southwest Research Station, Albany, CA. 29 p.

Ogden, A., and J. Innes. 2008. Climate change adaptation and regional forest planning in southern Yukon, Canada. *Mitig. Adapt. Strateg. Global Change* 13(8):833–861.

Peterson, D.L., C.I. Millar, L.A. Joyce, M.J. Furniss, J.E. Halofsky, R.P. Neilson, and T.L. Morelli. 2011. *Responding to climate change on national forests: A guidebook for developing adaptation options*. USDA For. Serv., Gen. Tech. Rep. PNW-GTR-855, Pacific Northwest Research Station, Portland, OR. 109 p.

Rexrode, C.O., and D. Brown. 1983. *Oak wilt*. USDA For. Serv., For. Insect and Dis. Leaflet 29, Northeastern Area State and Private Forestry, Newtown Square, PA. Available online at www.na.fs.fed.us/spfo/pubs/fidls/oakwilt/oakwilt.htm; last accessed Mar. 15, 2014.

Seppala, R., A. Buck, and P. Katila. 2009. *Adaptation of forests and people to climate change. A global assessment report.* International Union of Forest Research Organizations, Helsinki, Finland. 224 p.

Stankey, G.H., R.N. Clark, and B.T. Bormann. 2005. *Adaptive management of natural resources: Theory, concepts, and management institutions*. USDA For. Serv., Gen. Tech. Rep. PNW-GTR-654, Pacific Northwest Research Station, Portland, OR. 73 p.

Swanston, C.W., and M.K. Janowiak. 2012. *Forest adaptation resources: Climate change tools and approaches for land managers*. USDA For. Serv., Gen. Tech. Rep. NRS-87, Northern Research Station, Newtown Square, PA. 121 p. Available online at www.nrs.fs.fed.us/pubs/40543; last accessed Mar. 15, 2013.

Swanston, C., M.K. Janowiak, L. Iverson, L. Parker, D. Mladenoff, L. Brandt, P. Butler, et al. 2011. *Ecosystem vulnerability assessment and synthesis: A report from the climate change response framework project in Northern Wisconsin*. USDA For. Serv., Gen. Tech. Rep. NRS-82, Northern Research Station, Newtown Square, PA. 142 p. Available online at www.treesearch.fs.fed.us/pubs/38255; last accessed Mar. 15, 2013.

Vose, J.M., D.L. Peterson, and T. Patel-Weynand (eds.). 2012. *Effects of climatic variability and change on forest ecosystems: A comprehensive science synthesis for the US forest sector.* USDA For. Serv., Gen. Tech. Rep. PNW-GTR-870, Pacific Northwest Research Station, Portland, OR. 265 p.

Wisconsin Department of Natural Resources. 2013. *Oak wilt.* Available online at dnr.wi.gov/topic/foresthealth/oakwilt.HTML; last accessed Nov. 25, 2013.

Williams, B.K., R.C. Szaro, and C.D. Shapiro. 2007. *Adaptive management: The US Department of the Interior technical guide.* US Department of the Interior, Adaptive Management Working Group, Washington, DC. 86 p.