CHAPTER 2: ADAPTATION STRATEGIES AND APPROACHES

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A wealth of information is available on climate change adaptation, but much of it is very broad and of limited use at the finer spatial scales most relevant to land managers. This chapter contains a "menu" of adaptation actions and provides land managers in northern Wisconsin with a range of options to help forest ecosystems adapt to climate change impacts (Box 4). Land managers may select strategies and approaches from this menu based on their management goals and needs. This chapter also provides a basis for the Adaptation Workbook (Chapter 3), where managers consider local site conditions, climate change vulnerabilities, and other factors to further refine adaptation approaches into specific tactics that can be implemented on the ground.

About the Adaptation Strategies and Approaches

Information on how to adapt natural ecosystems to the anticipated effects of climate change is rapidly growing as increasing numbers of land managers engage with the topic (e.g., Gunn et al. 2009, Heinz Center 2008, The Nature Conservancy [TNC]

Box 4: Using the Adaptation Strategies and Approaches

The Adaptation Strategies and Approaches can:

- Present a full spectrum of possible adaptation actions that can help sustain forests and achieve management goals in the face of climate change.
- Serve as a "menu" of adaptation actions—managers select actions best suited to their specific management goals and objectives.
- Provide co-workers, team members, and other collaborators with a platform for discussion of climate change-related topics and issues.

The Adaptation Strategies and Approaches do not:

- Make recommendations or set guidelines for management decisions.
- Express preference for use of any of the strategies and approaches within a forest type, location, or situation. Rather, a combination of location-specific factors and manager expertise is meant to inform the selection of any strategy or approach.

2009). Much of this information, however, remains broadly applicable across ecosystem types without regard to geographic setting and does not provide sufficient detail for forest managers to identify specific response actions. We have compiled and synthesized a list of regionally focused strategies and approaches that may be used to adapt the forests of northern Wisconsin to a range of anticipated climate conditions and ecosystem impacts.

Importantly, the adaptation strategies and approaches presented in this chapter are nested within the existing paradigm of sustainable forest management. A changing climate and the associated uncertainty will create many challenges, forcing managers to be flexible and make adjustments to management objectives and techniques; however, the overarching goal of sustaining forests over the long term will remain a cornerstone of management. Many actions to adapt forests to climate change are consistent with sustainable management (Innes et al. 2009, Ogden and Innes 2008) and efforts to restore ecosystem function and integrity (Harris et al. 2006, Millar et al. 2006). Additionally, many current management activities make positive contributions toward increasing forest health and resilience in the face of climate change.

The strategies and approaches in this document are part of a continuum of adaptation actions ranging from broad, conceptual application to practical implementation (Fig. 6). They were synthesized from many scientific papers that discussed adaptation actions at numerous scales and locations (Appendix 2). Feedback from experts, including regional scientists, forest ecologists, and others, was used to refine the strategies and approaches and to provide information about the potential use of approaches for individual forest types in northern Wisconsin (Table 1).

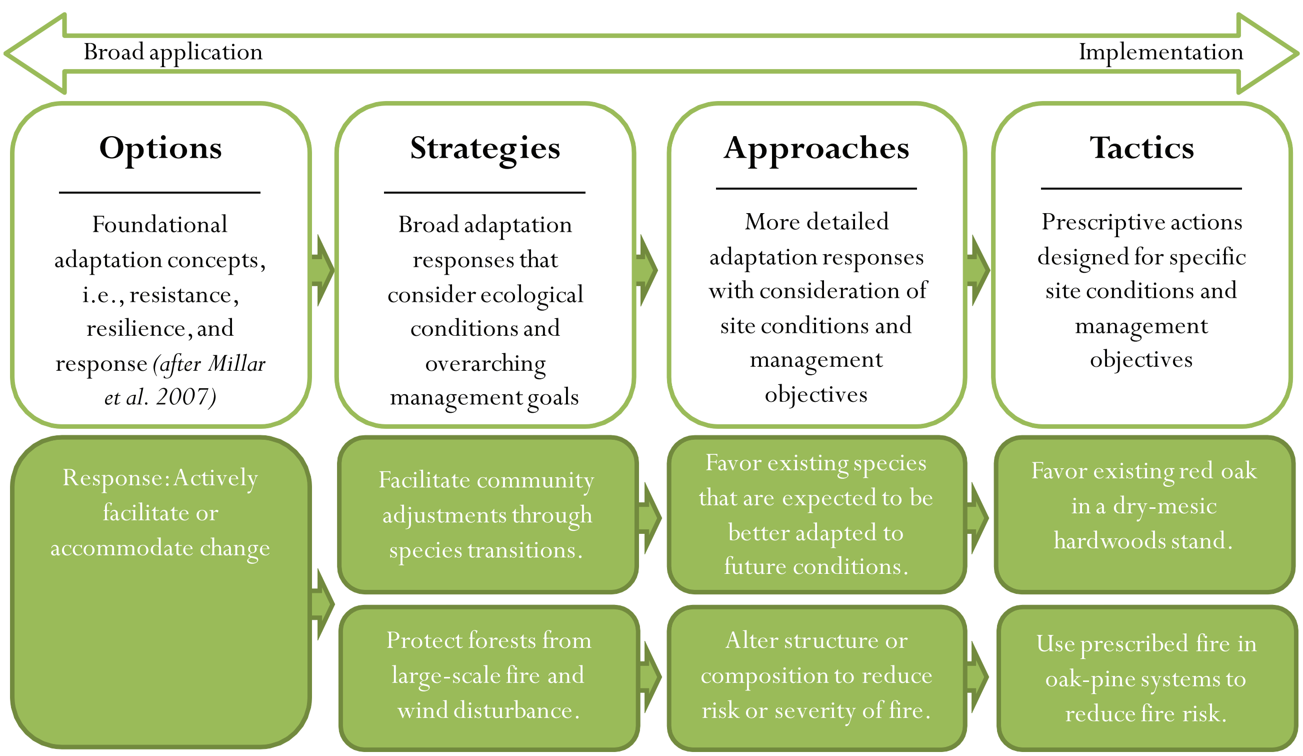

Figure 6.—A continuum of adaptation actions is available to address needs at appropriate scales and levels of management (top). The shaded boxes provide examples of each level of action (bottom). (Modified from Janowiak et al. 2011.)

Table 1.—Descriptions of the forest types present in northern Wisconsin. Common and scientific names for species are presented in Appendix 3.

Aspen – Dominated by quaking aspen, bigtooth aspen, or balsam poplar. Some stands may have co-dominant tree species such as balsam fir or white spruce.

Balsam Fir – Dominated by balsam fir. Some stands may include a component of quaking aspen or paper birch.

Hemlock – Dominated by eastern hemlock. Yellow birch and sugar maple are sometimes co-dominant.

Jack Pine – Stands are generally dominated by jack pine, with some stands being composed primarily of mixed pine species or on a rare occasion Scotch pine. Oak species may be co-dominant in some stands.

Lowland Conifer – Stands in lowland sites that are dominated primarily by black spruce, northern white-cedar, tamarack, or a mixture of these conifer species. Quaking aspen, paper birch and other species may be co-dominant in some stands.

Lowland Hardwood – Stands in lowland sites that are dominated primarily by black ash, red maple, or American elm, or a mixture of these species.

Northern Hardwood – Stands composed largely of sugar and red maple. Hemlock, yellow birch, basswood, red oak, and black cherry are also likely to be found in varying amounts, depending on site conditions.

Oak – Dominated by one or more oak species. Aspen, white pine, and other species may be co-dominant in some stands.

Paper Birch – Dominated by paper birch. Some stands may contain components of aspen or balsam fir.

Red Pine – Dominated by red pine. Some stands have an oak component in the understory and sometimes oak is a co-dominant.

Spruce – Generally dominated by white spruce (occasionally black spruce or Norway spruce). Some white spruce stands may have co-dominant tree species, such as balsam fir or quaking aspen.

White Pine – Dominated by eastern white pine. Some stands may include a component of hemlock or northern red oak and white ash.

At a broad level, the strategies presented below vary in their emphasis on resisting potential changes, building resilience, or actively responding to accommodate change (Table 2). The approaches nested under each strategy further vary in management intensity and style, emphasis on form or function, and reliance on traditional or experimental techniques. Some are more oriented toward passively adjusting to forest changes, while others seek to more actively guide changes. The challenge is to select the approaches that not only meet existing management goals, but also help prepare forests for a range of potential future climates and conditions.

The level of detail provided in this chapter helps tailor the approaches to the ecosystems of this region. A single adaptation approach may be applicable for many forest types but be executed in very different ways in each individual forest type. However, it is critical to keep in mind that site conditions, forest types, and management history and goals will all influence whether an approach is appropriate for a particular situation. Not all approaches can or should be used in every location or situation; rather, when a range of adaptation options (i.e., resistance, resilience, and response) exist, some of the approaches may be mutually exclusive or generally counteract each other.

We have added text to many of the approach descriptions that highlight examples or special considerations within a given forest type to help address the different ways in which an approach may be applied. We provide examples to describe how an approach might be implemented in order to spur the generation of other examples or applications. We also provide considerations for using the approach in specific forest types. These considerations are not exhaustive, and there are likely to be many more considerations unique to a forest type than are provided. Similarly, even if a forest type is not specifically highlighted, the approach may still be considered for use.

Table 2.—Climate change adaptation strategies under three broad adaptation options.

Strategy	Resistance	Resilience	Response
1. Sustain fundamental ecological functions.	X	X	X
2. Reduce the impact of existing biological stressors.	X	X	X
3. Protect forests from severe fire and wind disturbance.	X	X	
4. Maintain or create refugia.	X		
5. Maintain and enhance species and structural diversity.	X	X	
6. Increase ecosystem redundancy across the landscape.		X	X
7. Promote landscape connectivity.		X	X
8. Enhance genetic diversity.		X	X
9. Facilitate community adjustments through species transitions.			X
10. Plan for and respond to disturbance.			X

Adaptation Strategies and Approaches

Strategy 1: Sustain fundamental ecological functions

Climate change will have substantial effects on a suite of ecosystem functions, and many management actions will need to work both directly and indirectly to maintain the integrity of ecosystems in the face of climate change. This strategy seeks to sustain fundamental ecological functions, including those related to soil and hydrologic conditions. Adaptation approaches under this strategy should be used in concert with other approaches to maintain ecosystem productivity and health, as well as to meet management goals and objectives.

Approaches:

Maintain or restore soil quality and nutrient cycling

Northern Wisconsin is experiencing increased temperatures (Kucharik et al. 2010), which correspond to shorter periods of snow cover and frozen water and soils. Maintaining both soil quality and nutrient cycling in forest ecosystems is already a common tenet of sustainable forest management (e.g., Wisconsin Department of Natural Resources [WDNR] 1995), and continued vigilance will help improve the capacity of the forest to persist under new conditions. Re-evaluation of the timing and intensity of some practices will help ensure that site quality is not degraded as both ecosystem vulnerabilities and the duration of seasons change. One example of an adaptation tactic under this approach is to alter the timing of logging operations to prevent soil compaction, realizing that the time when soils will be frozen or protected by snowpack is decreasing (Gunn et al. 2009). Another example of a tactic is to retain coarse woody debris in order to maintain moisture conditions, soil quality, and nutrient cycling (Covington 1981, Duvall and Grigal 1999).

Additional considerations for individual forest types under this approach include:

- **Aspen:** This forest type is expected to be sensitive to increased temperature and decreased precipitation (Burns and Honkala 1990). Aspen on very dry sites may undergo reduced productivity or vigor as growing seasons continue to lengthen, possibly combined with increased late-season drought.

- **Lowland Conifer:** Very moist soils are critical for this forest type, making it especially susceptible to soil compaction and rutting. Actions to modify timing of entry, equipment, or technique may help to minimize these impacts where optimal windows for winter harvest (e.g., under frozen soil conditions) are shorter as a result of climate change.
- **Spruce:** White spruce tends to be shallow rooted and prefers moist sites. Actions to modify timing of entry, equipment, or technique may help to minimize these impacts where optimal windows for winter harvest (e.g., when snowpack is 6 inches or more) are shorter as a result of climate change.

Maintain or restore hydrology

Some forest types, such as lowland hardwoods and lowland conifers, are very susceptible to drought and may become more vulnerable as a result of climate change. Conversely, other forest types are susceptible to flooding and ponding, which may occur more often as a result of more frequent severe weather events. In order to maintain appropriate hydrologic regimes within systems, existing infrastructure that diverts water or otherwise alters hydrology can be reevaluated to compensate for changes in water levels or flows. It is important to keep in mind that modifications that maintain hydrology at one site may negatively impact hydrology at another site. Examples of adaptation tactics under this approach include minimizing road networks, adjusting culvert size requirements for changes in peak flow, and planning for seasonal limitations on heavy equipment.

Additional considerations for individual forest types under this approach include:

- **Lowland Conifer, Lowland Hardwood:** Maintaining sufficient water level and movement are critical to forest productivity in these forest types and influence species composition. Actions to modify road networks, culverts, or other control points to account for changes in water flow resulting from climate change may help to maintain suitable hydrologic conditions.

Maintain or restore riparian areas

Riparian forests help to buffer stream temperatures as well as increase landscape connectivity for the migration of species (Heller and Zavaleta 2009). The use of best management practices and riparian management zones can be used to avoid damage to riparian areas during management activities. An example of an adaptation tactic under this approach would be to promote conifer species in order to maintain cooler stream temperatures and stream shading. Another example focused at a landscape level could include the reforestation of riparian areas in agricultural areas to reduce erosion into adjacent water bodies.

Additional considerations for individual forest types under this approach include:

- **Balsam Fir, Hemlock, Lowland Conifer:** These forest types often occur in or adjacent to riparian areas. Many conifer species are projected to decline as a result of climate change, and riparian areas may serve as natural refugia for these species.
- **Lowland Hardwood:** Longer growing seasons and drier conditions late in the growing season may result in lower water tables and increased stress on riparian ecosystems. A decline in riparian tree cover may result in a greater increase in stream temperatures and increase the risk of erosion. Actions to manage water levels, such as through the manipulation of existing dams and water control structures, may help to supply proper soil moisture to forests adjacent to the stream during critical time periods.

Strategy 2: Reduce the impact of existing biological stressors

Biological stressors such as insects, pathogens, invasive species, and herbivores can act individually and in concert to amplify the effects of climate change on ecosystems. Forest managers already work to maintain the ability of forests to resist stressors; as an adaptation strategy, these efforts receive added focus and resources, with an emphasis on anticipating and preventing increased stress before it occurs. Dealing with these existing stressors is one of the most valuable and least risky strategies available for climate change adaptation, in part because of the large existing body of knowledge about their impacts and solutions (Climate Change Wildlife Action Plan Work Group 2009).

Approaches:

Maintain or improve the ability of forests to resist pests and pathogens

Even modest changes in climate may cause substantial increases in the distribution and abundance of many forest insects and pathogens (Ayres and Lombardero 2000, Dukes et al. 2009). These impacts may be exacerbated where site conditions, climate, other stressors, and interactions among these factors increase the vulnerability of forests to these agents. Actions to manipulate the density, structure, or species composition of forests may reduce the susceptibility of forests to some pests and pathogens. One example of an adaptation tactic under this approach is to discourage infestation of certain insect pests by reducing the density of a host species and increasing the vigor of the remaining trees. Another example is to maintain an appropriate rotation length to decrease the period of time that a stand is vulnerable to insect pests and pathogens (Spittlehouse and Stewart 2003), recognizing that species are uniquely susceptible to pests and pathogens at various ages and stocking levels. Existing management tactics can also be used to reduce the susceptibility of forests to insects and diseases that may be exacerbated by climate change (Coakley et al. 1999).

Photo by Maria K. Janowiak, U.S. Forest Service and Northern Institute of Applied Climate Science

Tamarack trees on the edge of a small peatland.

Prevent the introduction and establishment of invasive plant species and remove existing invasives

A number of invasive plant species are currently a threat to the forests of northern Wisconsin (WDNR 2009), and climate change is expected to increase invasive species' rate of invasion and spread (Millar et al. 2007). Current recommendations for controlling invasives in forests emphasize early detection of and rapid response to new infestations. An example of a tactic already in practice in northern Wisconsin is the use of guidelines to prevent the spread of invasives by equipment during site preparation or harvesting (WDNR 2009).

Manage herbivory to protect or promote regeneration

Climatic changes may increase the potential for herbivory if populations are able to increase under warmer conditions (Dale et al. 2001, Wisconsin Initiative on Climate Change Impacts [WICCI] 2011b). While many herbivores are present in northern Wisconsin, including insects, rodents, and ungulates, much of the information that is currently available focuses on white-tailed deer (e.g., Waller and Alverson 1997, Waller 2007). Deer herbivory is currently a stressor in some northern Wisconsin forests (Mladenoff and Stearns 1993, Rooney and Waller 2003, WDNR 2010), and there is potential for herbivory to increase in extent and intensity if projected changes in climate lower winter mortality and allow deer populations to grow (WICCI 2011b). As climate change exacerbates many forest stressors, it will be increasingly important to protect regeneration of desired species from deer and other herbivores. An example of an existing tactic that is sometimes employed to influence landscape-level deer use is to perform timber harvests in upland forests to reduce deer migration toward adjacent lowland conifer forests, where regeneration is highly vulnerable to browse. Examples of adaptation tactics at the stand level include the use of fencing and other barriers, as well as "hiding" more desirable species in a mixture of less palatable ones.

Additional considerations for individual forest types under this approach include:

- **Hemlock, Lowland Conifer, Red Pine, White Pine:** Conifer species within these forest types are expected to experience declines in suitable habitat as a result of climate change. Actions to reduce deer browse where it is likely to hinder regeneration of desired species may be especially valuable for helping these species persist under changed conditions.

Strategy 3: Protect forests from severe fire and wind disturbance

Climate change is projected to increase the frequency and severity of droughts and severe weather (Intergovernmental Panel on Climate Change 2007, WICCI 2011b), potentially leading to increased risk of many disturbances, including fire, wind storms, and ice storms (Dale et al. 2001). These disturbances can alter forests over large landscapes and strongly interact with many other stressors. Even as trends continue to emerge, management will need to adjust appropriately to the changes in natural disturbance dynamics (Heller and Zavaleta 2009).

Approaches:

Alter forest structure or composition to reduce risk or severity of fire

Current forest structure and composition may interact with longer and drier growing seasons to increase the risk of fire and associated disturbances (e.g., insect and pathogen outbreaks leading to tree mortality and increased fire risk). Forest management actions to alter species composition or stand structure may increase stand vigor and reduce susceptibility to these threats. An example of an adaptation tactic under this approach is the use of prescribed burning or other ground cover management to minimize fuel loading and reduce the severity of potential fires (Ogden and Innes 2008, Spittlehouse and Stewart 2003). Another example is to plant fire-resistant species, such as hardwoods, between more flammable conifers to reduce vulnerability to wildfires (Spittlehouse and Stewart 2003); this tactic would need to be implemented now to be effective several decades in the future.

Establish fuelbreaks to slow the spread of catastrophic fire

Projected increases in fire as a result of climate change are expected to increase demand on fire-fighting resources and may force prioritization of fire suppression efforts to targeted areas (Millar et al. 2007, Spittlehouse and Stewart 2003). A fuelbreak is defined as a physical barrier to the spread of fire, such as a road, bulldozer line, or body of water; it can also be defined as a change in composition and density of a forest at its edges to reduce fuels. Fuelbreaks can be created to lessen fire spread and intensity in specific areas, such as the wildland-urban interface. Where this approach is designed to protect areas of high value or high concern, the potential for increased forest fragmentation may also be a consideration. An example of an adaptation tactic under this approach is to create a fuelbreak between a flammable or fire-adapted stand and a stand where fire would be undesirable; for example, planting maple between lowland conifer forests and upland fire-prone oak forests may prevent surface fires from moving through the moisture-rich maple leaf litter (Agee et al. 2000). An example of a tactic that is already in practice in northern Wisconsin is to reduce the density of balsam fir (a ladder fuel) in wildland-urban interface areas or near power lines to reduce the spread of fire.

Additional considerations for individual forest types under this approach include:

- **Jack Pine:** Wildfire in jack pine can be difficult to control (Carey 1993). Actions to reduce the risk of large and severe fire, such as the creation of physical fire breaks, in this forest type may help protect refugia or other areas.
- **Lowland Conifer:** Changes in temperature, precipitation, and hydrology may make this system more susceptible to wildfire. The establishment of physical fuelbreaks that displace wetland soils, such as bulldozer lines, has the potential to negatively affect soil structure or hydrology if actions are not taken to minimize impacts.

Alter forest structure to reduce severity or extent of wind and ice damage

Wind disturbances are a fundamental process in many forest ecosystems of the Great Lakes region (Frelich 2002). Wind events and the ensuing effects on forests are expected to become more frequent and severe under climate change (Fischlin et al. 2009, Frelich and Reich 2010), although there are many challenges in predicting the size, frequency, and intensity of these events (Peterson 2000). Some stands may have structures poorly suited to withstand projected increases in storm intensity. Silvicultural techniques exist to alter forest composition and structure for increased resistance to blow-down during severe wind events, although fewer techniques may be available to reduce potential for ice damage. An example of a tactic that is already in practice in northern Wisconsin is to retain trees at the edge of a clearcut to help protect trees in the adjacent stand that have not been previously exposed to wind.

Strategy 4: Maintain or create refugia

Refugia are areas that have resisted ecological changes occurring elsewhere, often providing suitable habitat for relict populations of species that were previously more widespread (Millar et al. 2007). For example, during previous periods of rapid climate change, at-risk populations persisted in refugia that avoided extreme impacts on climate (MacDonald et al. 1998, Millar et al. 2007, Noss 2001). Refugia enable long-term retention of plants, which can then be used to augment the establishment of new forests. This strategy seeks to identify and maintain ecosystems that: (1) are on sites that may be better buffered against climate change and short-term disturbances, and (2) contain communities and species that are at risk across the greater landscape (Millar et al. 2007, Noss 2001). Refugia may or may not function as reserve areas; management activities may be needed to create or maintain refugia.

Approaches:

Prioritize and protect existing populations on unique sites

Some northern Wisconsin ecosystems, such as lowland forests and ephemeral ponds, may be more vulnerable to the impacts of climate change due to their dependence on a narrow range of site conditions. Soil characteristics, hydrologic conditions, topographic variation, and other characteristics may provide conditions that retain habitat for native species and resist invasive species. Existing ecosystems may be more easily maintained at sites with these unique conditions. An example of an adaptation tactic under this approach that focuses on prioritization is to identify unique sites that are expected to be more resistant to change, such as spring-fed stands sheltered in swales, and emphasize maintenance of site quality and existing communities. A more active adaptation tactic is to identify a suite of potential sites for refugia and commit additional resources to ensuring that the characteristic conditions are not degraded by invasive species, herbivory, fire, or other disturbances.

Photo by Maria K. Janowiak, U.S. Forest Service and Northern Institute of Applied Climate Science

Fiddleheads in a spring forest.

Additional considerations for individual forest types under this approach include:

- **Lowland Conifer, Lowland Hardwood:** Lowland systems may be at risk from drier conditions and encroachment of upland species. At the same time, options for maintaining these types under climate change are limited by the need for specific hydrologic conditions. Identifying and establishing refugia will likely provide the best opportunity for maintaining lowland systems on the landscape because few adaptation approaches will be effective in this forest type. Maintaining these systems as refugia may require active management of water levels and species composition.

Prioritize and protect sensitive or at-risk species or communities

Northern and boreal species are widespread in northern Wisconsin, but are likely to lose habitat because they are already at the southern extent of their range (Swanston et al. 2011). By prioritizing maintenance of sensitive and at-risk species or communities, managers can sustain these species on-site for as long as possible or until new long-term sites can be located and populated. An example of an adaptation tactic under this approach is to identify and protect high-quality stands of hemlock or other desired forest types to serve as refugia identified for long-term maintenance of the type. This approach could also be used to identify and create refugia for threatened and endangered plant or animal species.

Additional considerations for individual forest types under this approach include:

- **Aspen, Balsam Fir, Hemlock, Paper Birch, Spruce:** Many species in these forest types are projected to decline as a result of climate change; identifying refugia may be particularly important for maintaining these types on the landscape. Cooler and wetter sites such as riparian areas, north-facing slopes, lake edges, and wetlands may have suitable site conditions and may be less likely to be impacted by human-caused or natural disturbances.
- **Northern Hardwood:** Higher species diversity in this forest type increases its overall adaptive capacity, but several individual species are expected to decline. Actions to establish refugia on cooler and moister microhabitats may help maintain desired plant communities that are at risk from climate change.

Establish artificial reserves for at-risk and displaced species

Species already exist outside their natural habitats in nurseries, arboretums, greenhouses, and botanical gardens across the world. These artificial reserves may be used to support individuals or genetic lineages that are no longer able to survive in their former location (Fiedler and Laven 1996, Millar 1991). These highly controlled environments could act as interim refugia for rare and endangered plant species that have specialized environmental requirements and low genetic diversity (Heinz Center 2008, Spittlehouse and Stewart 2003). This idea of interim refugia to maintain species until they can be moved to new locations would likely require substantial resources to pursue (Coates and Dixon 2007). An example of an adaptation tactic under this approach is to use an existing artificial reserve to cultivate southern species whose suitable habitat has moved northward, but who face considerable lag time before new habitat may become available.

Strategy 5: Maintain and enhance species and structural diversity

Species and structural diversity may buffer a system against the susceptibility of individual components to changes in climate. Forest managers already work to increase structural and species diversity; as an adaptation strategy, this general goal receives added effort and focus. A system may still experience stress as individual components fare poorly, but the overall system can be made more resilient.

Approaches:

Promote diverse age classes

Species are vulnerable to stressors at different stages in the species life cycle. Maintaining multiple age classes of a species will help increase structural diversity within stands or across a landscape, as well as buffer vulnerability to stressors of any single age class. Monocultures and even-aged stands are often more susceptible to insect pests and diseases, many of which are likely to increase in range and severity as a result of climate change; maintaining a mosaic of even-aged stands of varying ages across the landscape will increase diversity in these forest types.

Maintain and restore diversity of native tree species

Diverse forests may be less vulnerable to climate change impacts because they distribute risk among multiple species, reducing the likelihood that the entire system will decline even if one or more species suffers adverse effects. This relationship may be especially important in forest types with low diversity; even small increases in diversity may increase resilience without greatly altering species composition or successional stage. Climate change may exacerbate adult mortality or induce regeneration failure of northern species (Swanston et al. 2011). Actions to promote and enhance regeneration of native species through understory management and planting efforts may help to maintain diverse and vigorous native communities.

Retain biological legacies

Biological legacies of desired species can facilitate persistence, colonization, adaptation, and migration responses to climate change (Gunn et al. 2009). Silvicultural treatments designed to retain biological legacies can be conducted to create diversity in structure, species composition, and unique characteristics while maintaining the appropriate density of desired species. An example of a tactic that is already in practice in northern Wisconsin is to retain individual trees of a variety of species to maintain their presence on the landscape. This tactic could also be used to provide both a potential seed source for species and genotypes that are expected to be better adapted to future conditions, as well as future nurse logs for regeneration of some species (Gunn et al. 2009).

Restore fire to fire-adapted ecosystems

Long-term fire suppression leads to shifts in forest structure and composition, which may disproportionately favor a smaller number of species and reduce biodiversity (Tirmenstein 1991). Restoring fire regimes that attempt to mimic natural disturbance in fire-adapted systems can enhance regeneration and encourage stronger competition by fire-dependent and fire-tolerant species (Abrams 1992). Repeated low-intensity fire in some forest types, such as red pine and oak, can emulate natural processes to foster more complex stand structures while reducing risk of severe fire. An example of an adaptation tactic under this approach is to use prescribed fire to reduce ladder fuels and lower risk of large and severe wildfire in areas that are expected to have increased fire risk as a result of climate change.

Establish reserves to protect ecosystem diversity

Some areas with exemplary combinations of soil, hydrologic, and climatic variation support a correspondingly high degree of species diversity. Ecosystem diversity in these areas may be protected by establishing reserves, traditionally defined as natural areas with little to no harvest activity that do not exclude fire management or other natural disturbance processes (Halpin 1997). The use and definition of reserves should be considered carefully within the context of changing climate and forest response as some systems may greatly benefit from minimal intrusion, whereas others may actually require more active management if ecosystem integrity begins to deteriorate. It may be valuable to retain explicit flexibility in management practices, so long as management directly supports the justifications and goals for establishing the reserve.

Additional considerations for individual forest types under this approach include:

- **Aspen, Jack Pine, Paper Birch:** This approach may not be well-suited to these forest types because they require frequent and active management to be maintained in an early-successional stage.

Strategy 6: Increase ecosystem redundancy across the landscape

Some losses are inevitable, whether due to catastrophic events or unforeseen interactions of management, climate change, and forest response. Increasing ecosystem redundancy attempts to lower the overall risk of losing a forest type by increasing the extent of the forest type, the number of occurrences of the forest type across the landscape, and the diversity of regeneration stages.

Approaches:

Manage habitats over a range of sites and conditions

The suitable site conditions for a forest type or species may shift on the landscape as climate changes. Spreading forest types over a range of sites and conditions, both existing and new, will increase combinations of location, site conditions, and species aggregations. Opportunities for successful regeneration and the likelihood of persistence of a

Photo by Maria K. Janowiak, U.S. Forest Service and Northern Institute of Applied Climate Science

A managed jack pine stand.

species or community may thus be increased (Joyce et al. 2009, Millar et al. 2007, TNC 2009).

Additional considerations for individual forest types under this approach include:

- **Aspen, Jack Pine, Northern Hardwood:** These forest types are currently widespread across a range of sites and conditions, but expected to decline. The current extent may provide many options for retaining redundancy across the landscape.

Expand the boundaries of reserves to increase diversity

Certain areas contain exemplary combinations of soil, hydrologic, and climatic variation, with a correspondingly high degree of species diversity. An earlier approach (Establish reserves to protect ecosystem diversity) describes choosing areas such as these to establish reserves, which are traditionally defined as natural areas with little to no harvest activity that do not exclude fire management or other natural disturbance processes (Halpin 1997). Expanding existing reserve boundaries may buffer and replicate the diversity within the core of the reserve, but more importantly, may also increase the overall variation in species within the expanded reserve.

Strategy 7: Promote landscape connectivity

Species migration is a critical factor in the ability of forests to maintain ecosystem function in a changing climate; however, fragmentation of landscapes and loss of habitat may restrict species movements and gene flow (Davis and Shaw 2001). Managing the landscape for connectivity will allow for easier movement, reduce lags in migration, and enhance genetic diversity. This approach benefits both wildlife and forests (e.g., squirrels provide the movement of acorns across the landscape). Connectivity also increases movement of invasives and pests, however, thereby increasing the need for vigilance. Numerous factors contribute to today's migration patterns. The current rate of climate change, coupled with contemporary land use and demographics, creates challenges to migration that are unique to this period in time. Many species are not expected to be able to migrate at a rate sufficient to keep up with climate change and associated range shifts (Davis and Shaw 2001, Iverson et al. 2004), so when managers pursue this strategy, it may be beneficial to combine the approaches under this strategy with ones to create refugia (Strategy 4).

Approaches:

Use landscape-scale planning and partnerships to reduce fragmentation and enhance connectivity

Enabling species migration across the landscape and buffering against disturbance will require a concerted effort to create partnerships, agreements, and other mechanisms for land protection and management across property boundaries. Coordinating forest conservation easements and certification programs, and other efforts to increase the size and connectivity of forests will foster a landscape-level response to counter the widespread effects of climate change (Millar et al. 2007, Spittlehouse and Stewart 2003). Establishing management agreements across boundaries of reserves and managed forests will also allow for protection of species moving across the landscape (Heller and Zavaleta 2009).

Establish and expand reserves and reserve networks to link habitats and protect key communities

Areas containing exemplary combinations of soil, hydrologic, and climatic variation may have a correspondingly high degree of species diversity. An earlier approach (Establish reserves to protect ecosystem diversity) describes choosing these areas to establish reserves, traditionally defined as natural areas with little to no harvest activity that do not exclude fire management or other natural disturbance processes (Halpin 1997). Placing reserves adjacent to each other to form a network of a few large reserves, many small reserves along a latitudinal gradient, or a combination of large and small reserves close to each other will help maintain connectivity across a varied and dynamic landscape (Halpin 1997, Heller and Zavaleta 2009, Spittlehouse and Stewart 2003). Designating buffer zones of low-intensity management around core reserve areas and between different land uses may allow greater flexibility in silvicultural treatments of adjacent lands, promote species movement, and help protect core areas from disturbance.

Maintain and create habitat corridors through reforestation or restoration

The presence of both small and large corridors on the landscape may help slow-moving species to migrate without additional assistance. Establishing or restoring forest cover along natural features, such as rivers, or property lines may improve species' ability to naturally adapt and migrate (Heller and Zavaleta 2009). Corridors oriented in any direction may be useful to facilitate genetic mixing, but corridors arranged north-south may be more useful if the goal is to allow for species movements along the climatic gradient.

Additional considerations for individual forest types under this approach include:

- **Lowland Conifer, Lowland Hardwood:** Climate change is likely to alter the hydrologic conditions required by these forest types. Reforestation or restoration of riparian areas may help retain these species on the landscape longer while providing a forested corridor.
- **Northern Hardwood:** This forest type could serve as a matrix to connect many forest types across the landscape because it is currently abundant and relatively contiguous in northern Wisconsin. These forests can be used as migration routes for southern species to move northward.

Photo by Maria K. Janowiak, U.S. Forest Service and Northern Institute of Applied Climate Science

A northern flicker on the branch of a dead tree.

Strategy 8: Enhance genetic diversity

Climate has changed in the past, but the current rate of climate change is much more rapid than in the past (Davis and Shaw 2001, Woodall et al. 2009), and human dependence on ecosystem services may demand an active role in species migration and genetic adaptation (McLachlan et al. 2007). Greater genetic diversity within and among species may help species adjust to new conditions or sites, distributing the risk across a more diverse population. Actions to enhance genetic diversity could be timed to occur after large-scale disturbances to take advantage of regeneration and establishment phases. Approaches under this strategy are best implemented with great caution, incorporating due consideration of the uncertainties inherent in climate change, the sparse record of previous examples, and continued uncertainties of forest response. Initial attempts at implementation may be considered as early field trials rather than templates.

Approaches:

Use seeds, germplasm, and other genetic material from across a greater geographic range

Many key environmental factors that influence plant growth and reproduction are changing, including temperature, length of growing season, and the amount and seasonal pattern of precipitation (Post 2003). Out-planted nursery seedlings typically have greater survival when they originate from local seed sources, but these seed sources may no longer produce the best-adapted seedlings if the governing environmental factors change. Utilizing seed zones that change over time and are based on regional analyses of climate change data may provide better seed sources than static seed zones (Millar et al. 2007, Spittlehouse and Stewart 2003). This approach may entail importing seedlings from slightly farther away that are better adapted to current or future climatological conditions. Genetic sources may be limited for the many species that are currently at the southern edge of their range in northern Wisconsin. For other species, new genetic material may be available from sources to the south or west. It is important to note that although many environmental factors may match seedlings to geographic area, cold tolerance or other limitations may remain (Millar et al. 2007).

Favor existing genotypes that are better adapted to future conditions

Genotypes may be present within forests that are better adapted to future conditions because of pest resistance, broad tolerances, or other characteristics (Millar et al. 2007, Spittlehouse and Stewart 2003). However, the use of this approach may be currently limited by the uncertainty surrounding precise future conditions and which genotypes are best suited to these conditions. The use of this approach may also be limited by available source material. An example of an adaptation approach under this tactic is to collect seed from vigorous and healthy trees in locations that currently have conditions that are expected to be more prevalent in the future. Another example is to retain some vigorous survivors of a die-back event, such as drought-induced mortality, rather than salvage all trees in an affected area.

Increase diversity of nursery stock to provide those species or genotypes likely to succeed

Maintaining ecosystem function and diversity is largely dependent on successful seedling establishment, which may require historically unprecedented planting efforts in some locations. Changing climatic conditions will need to be paralleled by appropriate infrastructure and resources for regeneration, including the availability of genetically diverse material coming from seed orchards and nurseries (Millar et al. 2007). Because infrastructure and resources to support the development of new sources of stock may be limited, it may become more important to invest in nurseries that provide an array of species and genotypes that can both meet short-term demand for traditional species and enable long-term adaptation.

Strategy 9: Facilitate community adjustments through species transitions

Species composition in many ecosystems is expected to change as species adapt to a new climate and form new communities. This strategy seeks to maintain overall ecosystem function and health by gradually enabling and assisting adaptive transitions within forest communities. The result may be species assemblages slightly different from those present in the current forest type, or an altogether different forest type in future decades. Importantly, this strategy aims to maintain key ecosystem functions, not an unchanging community or species mix. Further, this strategy is unlikely to be applicable across the entire range of any forest type within the next several decades. Many of the approaches in this strategy attempt to mimic natural processes, but may currently be considered unconventional management responses. In particular, some approaches incorporate assisted migration, which remains a challenging and contentious issue (Janowiak et al. 2011, McLachlan et al. 2007). Caution is warranted in use of this strategy, and initial attempts at implementation may serve more as early field trials than as templates. Outcomes from early efforts to promote community transition can be evaluated to provide information on future opportunities for transitions, as well as effective methods and timing.

Approaches:

Anticipate and respond to species decline

Species on the southern and warmer edges of their geographic range are especially vulnerable to habitat loss, and some systems are expected to decline rapidly as conditions change. In northern Wisconsin, nearly all forest types contain dominant or common associate species that are expected to have substantial declines in suitable habitat under a changing climate (Swanston et al. 2011). Anticipating forest and species declines due to changes in climate, disturbance regimes, or other factors may help in developing early and appropriate management responses to maintain forest cover and ecosystem function. The species assemblage may be dramatically altered through active or passive means. An example of an adaptation tactic under this approach is to identify tree species that are very likely to decline or are already declining, and promote other species to fill a similar niche. For example, red maple and black cherry could be encouraged on a site that is expected to become drier to compensate for expected decreases in sugar maple dominance.

Additional considerations for individual forest types under this approach include:

- **Lowland Hardwood:** Lowland species are likely to be impacted by altered hydrology and precipitation patterns as a result of climate change (Swanston et al. 2011). Susceptibility to the emerald ash borer, however, may result in complete loss of forest cover in black ash-dominated sites long before climate change impacts are evident. Early promotion of other lowland hardwood species may buffer the decline of ash-dominated stands and help retain ecosystem function in the short term.

Favor or restore native species that are expected to be better adapted to future conditions

In many cases, native species may be well-adapted to the future range of climatic and site conditions. Using management to favor the native species in a forest type that are expected to fare better under future climate change can facilitate a shift in the species assemblage without drastically altering the forest composition. Although many forest types contain one or several dominant species that are expected to experience declines in suitable habitat (Swanston et al. 2011), other tree species may be able to be favored for their expected ability to do well under future conditions, such as red oak in the aspen, jack pine, and northern hardwood forest types. Where forests are dominated by a single species, this approach will likely lead to conversion to a different forest type, albeit with a native species.

Photo by Maria K. Janowiak, U.S. Forest Service and Northern Institute of Applied Climate Science

A stream winding through a northern hardwood forest.

Manage for species and genotypes with wide moisture and temperature tolerances

Inherent scientific uncertainty surrounds climate projections at finer spatial scales (Schiermeier 2010), making it necessary to base decisions upon a wide range of predictions of future climate. Managing for a variety of species and genotypes with a wide range of moisture and temperature tolerances may better distribute risk than attempting to select species with a narrow range of tolerances that are best adapted to a specific set of future climate conditions (TNC 2009).

Emphasize drought- and heat-tolerant species and populations

Some areas of northern Wisconsin have already experienced decreased summer precipitation over the last half century (Kucharik et al. 2010, WICCI 2011b). There is uncertainty about whether this trend will continue, but expected increases in large precipitation events may concentrate rainfall to fewer total events (Swanston et al. 2011, WICCI 2011b). In anticipation of warmer temperatures and potential for drought late in the growing season, it may be beneficial to emphasize drought- and heat-tolerant species in areas that may be most vulnerable to drought. An example of an adaptation tactic under this approach is to favor or establish oak species on narrow ridge tops, south-facing slopes with shallow soils, or other sites that are expected to become warmer and drier. Another example is to seed or plant drought-resistant genotypes of commercial species where there is an expectation of increased drought stress (Joyce et al. 2009).

Additional considerations for individual forest types under this approach include:

- **Aspen, Northern Hardwood:** Actions to promote oak, pine, and other more drought- and heat-tolerant species on drier sites where these species are already present as a minor component may help to reduce the vulnerability of these forest types.
- **Jack Pine:** This type is the most drought-tolerant forest type present in northern Wisconsin. While jack pine is projected to experience declines under future climate conditions, the species may fare better than the models predict (Swanston et al. 2011). Jack pine forest may be able to persist on many sites, including sites that currently do not host jack pine but may become more suitable in the future.

Guide species composition at early stages of stand development

Long-term ecosystem function may be jeopardized if existing and newly migrated species fail to regenerate and establish. Active management of understory regeneration may help forests make the transition to new and better-adapted compositions more quickly by reducing competition from undesirable, poorly-adapted, or invasive species. Natural disturbances often initiate increased seedling development and genetic mixing, and can be used to facilitate adaptation (Joyce et al. 2009). When forests are dominated by one or a small number of species, this approach may lead to conversion to a different forest type.

Additional considerations for individual forest types under this approach include:

- **Jack Pine, Paper Birch, Red Pine:** Under drier conditions and increased stress, promoting regeneration and discouraging competitors may require more intensive site preparation, including prescribed fire, soil disturbance, and herbicide use.

Protect future-adapted regeneration from herbivory

Herbivory from insects, rodents, ungulates, and other species may increase as a result of climate change (WICCI 2011b), potentially interacting with other agents to increase overall stress and reduce regeneration. Protecting desired regeneration of existing or newly migrated species can strongly shape the ways in which communities adapt (TNC 2009). In northern Wisconsin, herbivory from white-tailed deer is already a major determinant of species composition through direct effects on regeneration success (Waller and Alverson 1997, Waller 2007, WDNR 2010); therefore, efforts to counter herbivory may focus on deer in many locations. Examples of adaptation tactics under this approach include the use of repellent sprays, bud caps, or fencing to prevent browse on species that are expected to be well-adapted to future conditions.

Establish or encourage new mixes of native species

Novel combinations of climatic and site conditions may support mixtures of native species that do not currently occur together. While some species may not typically occur in the same forest type, they may have been together previously (e.g., butternut and American elm in the oak forest type; Rhemtulla et al. 2009). Novel mixing of native species may result in conversion to a newly defined or redefined forest type. This approach is best implemented with great caution, incorporating due consideration of the uncertainties inherent in climate change, the sparse record of previous examples, and continued uncertainties of forest response. Initial attempts at implementation may be considered as early field trials rather than templates.

Identify and move species to sites that are likely to provide future habitat

Climate may be changing more rapidly than some tree species can migrate, and the northward movement of species may be restricted by land use or other impediments between areas of suitable habitat (Davis and Shaw 2001, Iverson et al. 2004). Maintaining ecosystem function or making the transition to a better-adapted system may involve the active introduction of nonnative species or genotypes (McLachlan et al. 2007). Given the uncertainty about specific climate conditions in the future, the likelihood of success may be increased by relocating species with a broad range of tolerances (e.g., temperature, moisture) across a wide range of provenances. This approach is best implemented with great caution, incorporating due consideration of the uncertainties inherent in climate change, the sparse record of previous examples, and continued uncertainties about forest response. Initial attempts at implementation may serve more as early field trials than as templates.

Strategy 10: Plan for and respond to disturbance

Ecosystems may face dramatic impacts as a result of climate change-related alterations in disturbances, including fire, drought, invasive species, and severe weather events (Dale et al. 2001). Disturbances are primary drivers of some ecosystem dynamics (e.g., stand-replacing fire in jack pine and windthrow in northern hardwood forests; Johnson 1995), but changes in the frequency, intensity, and duration of disturbance events may create significant management challenges. Although it is not possible to predict and prepare for a single disturbance event, it is possible to increase overall preparedness for large and severe disturbances. Actions to respond to disturbance can take place in advance of, as part of, or following the event (Dale et al. 2001). Many of the best opportunities for addressing disturbance-related impacts may occur immediately after the disturbance event; having a suite of planned options in place may facilitate an earlier and more flexible response. This strategy asks forest managers to imagine the worst-case scenarios, consider new opportunities, and have plans in place to quickly and appropriately respond.

Approaches:

Prepare for more frequent and more severe disturbances

Disturbances are likely to occur outside historical patterns, and impacts on forest ecosystems may occur more frequently and be more severe. Documenting clear plans for how to respond to more frequent or severe disturbances in advance will allow for a faster, more thoughtful, better-coordinated response. An example of an adaptation tactic under this approach is to identify locations where a given forest type would be unlikely to successfully reestablish in the case of a severe disturbance event, and then develop response options for establishing better-adapted communities in these places should the event occur.

Additional considerations for individual forest types under this approach include:

- **Aspen, Paper Birch:** Stand-replacing disturbances are often beneficial to these forest types. However, these early-successional forest types may experience accelerated succession where small- and medium-scale disturbances break up areas of forest canopy to allow shade-tolerant species to establish.
- **Balsam Fir, Spruce:** The dominant species in these forest types have flammable needles and shallow roots, which make them highly susceptible to damage or mortality from fire and wind.
- **Jack Pine:** Jack pine forests require extensive site disturbance to regenerate and are generally favored by stand-replacing disturbances and recurring fires. However, drought or fire can kill young seedlings and untimely disturbances may interfere with regeneration.
- **Lowland Conifer:** Increased temperatures and reduced seasonal precipitation may dry wet soils and peatlands, leading to increased risk of wildfire.

Prepare to realign management of significantly altered ecosystems to meet expected future environmental conditions

Some ecosystems may experience significant disruption and decline, such that desired conditions or management objectives may no longer be feasible. Management of these systems may be realigned to create necessary changes in species composition and structure to better adapt forests to current and anticipated environments, rather than historical pre-disturbance conditions (Millar et al. 2007, Spittlehouse and Stewart 2003). Developing clear plans that establish processes for realigning significantly altered ecosystems before engaging in active management will allow for more thoughtful discussion and better coordination with other adaptation responses. An example of realignment that is currently occurring in northern Wisconsin is the replacement of failed spruce forests with jack pine, tamarack, and other species.

Promptly revegetate sites after disturbance

Potential increases in the frequency, intensity, and extent of large and severe disturbances may disrupt regeneration and result in loss of forest cover, productivity, or function in the long term. Prompt revegetation of sites following disturbance may help reduce soil loss and erosion, protect water quality, discourage invasive species, and improve aesthetic quality in the newly exposed areas.

Allow for areas of natural regeneration after disturbance

Although many areas may undergo site preparation or be replanted after severe disturbance, some areas can be set aside to allow for natural regeneration as a means to identify the well-adapted species and populations (Joyce et al. 2009). The use and monitoring of test or "control" areas of natural revegetation following disturbance may help inform managers regarding species that can successfully regenerate at a local level without intervention.

Maintain seed or nursery stock of desired species for use following severe disturbance

Disturbed areas may need to be reseeded or replanted with high quality, genetically appropriate, and diverse stock. Maintaining stock that represents a variety of environmental conditions across a broad geographic range may help to supply future-adapted species and genotypes when needed. Advanced planning can help to make materials more available and improve the ability to promptly respond to disturbances. This approach may be limited by the availability of infrastructure and resources. There is also uncertainty regarding which genotypes may be better suited to future conditions, and the development of new sources of stock may take decades.

Remove or prevent establishment of invasives and other competitors following disturbance

Disturbed sites are more susceptible to colonization by invasive species, which are expected to increase under climate change (Dukes et al. 2009, Hellman et al. 2008) and may outcompete regeneration of desired species (Joyce et al. 2009). Emphasizing early detection of and rapid response to new infestations may reduce competition and aid efforts to encourage successful regeneration of desired species. Nonnative species that have desirable characteristics and are not invasive may be a lower priority for removal, perhaps becoming desirable ("neo-native") species in the future (Millar and Brubaker 2006, Millar et al. 2007).