Extension Bulletin E-3221, July 2014

How the Climate Affects Forests

Forests are affected by the local climate, in addition to being affected by short-term weather events. Michigan's climate has been changing over the past several decades, and continued climate change could result in many impacts to forests in our state.

The Earth's climate is changing. Many trends have been tracked, some reaching back tens of thousands of years. Trees and forests are sensitive to a range of environmental conditions, including the climate. In addition to climate, there are other factors to which forests respond, such as human activities and management, biological relationships, and invasive pests. All of this creates a dynamic within which forests grow and change.

How much do climate factors need to change before forests change in a significant way? This question is almost impossible to answer, although there is no doubt about impending change. Climate influences will vary between different forest types and will be complicated by ecological complexities.

Evidence of Change

Historical data goes back about one hundred years for some climate measures. There are a variety of ways climate factors can be inferred, such as pollen cores in bogs and the study of tree rings. Globally, some measures go back 100,000 years. Records over the past 100 years demonstrate some remarkable trends that cannot be attributed to natural causes. These trends vary somewhat across regions, but the overall picture points to a warming, more erratic climate.

Across the entire state, Michigan's average annual temperature increased over 2.4 ^{o}F from 1895-2013.[1] Winter temperatures have risen faster (3.3 ^{o}F) during the same time, particularly winter low temperatures (3.7 ^{o}F). Extreme high temperature periods have increased across the Midwest, including higher night temperatures and higher humidity.

Average annual precipitation has increased by 3.5 inches, with the greatest increases in the summer and fall. [1] There is variation across the state, with some areas experiencing significant droughts. The interaction of temperature, precipitation, and seasonality is important to forests.

Heavy rainfall events (+3 inches in a single event) have become more frequent in Michigan, as well as across the Midwest.[2] As a greater proportion of precipitation is delivered in large events, there can be longer periods between rain events.

Recent severe events, such as the burst of tornadoes across southern Michigan in 2012 and the northward migration of tornadoes suggest change but long-term records for these phenomena are limited.[3]

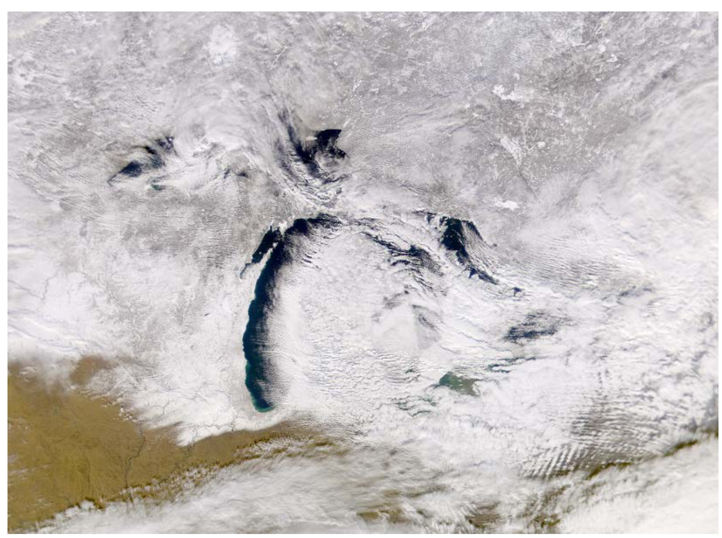
Effects on Forests

How does the climate affect forests? There are many direct and indirect ways. An example of a direct effect might be changes in phenology, for example when trees leaf-out in the spring or when flower buds open. An indirect effect might be the damage done by an insect whose range expands due to warmer winters.

Many forest processes are regulated by photoperiod and less driven by climate change. Other processes are influenced by temperature and other weather variables. The timing of leaf expansion is a common example. Dr. Andy Burton (Michigan Technological University) has observed that sugar maple growing season length has increased by 11.5 days over the past 20 years across a range of sites in Michigan.[4]

Forests are ecological systems that may be slow to respond to climate change. Much of the change is not predicted to occur until the middle of this century. In particular, mature trees are long-lived organisms and may not be good indicators of climate change. However, tree regeneration patterns may be early indicators, especially along ecotones of change (e.g. forest-prairie, hardwood-boreal). Regeneration of red maple and black ash is occurring in certain boreal forests, which is not typical.[5] Studies are underway examining changes across ecotones in Michigan, Wisconsin, and Minnesota.

More mobile taxa, such as birds and mammals, have experienced expansions in ranges.[6] These wildlife species serve important roles in the distribution and success of forest regeneration. Moose populations have declined across most of their southern range. Warmer temperatures are an important driver of that dynamic.[7]



Michigan's climate is influenced by the Great Lakes. Forests in Michigan are adapted to areas of lake-effect snowfall and characteristic winter weather. Image courtesy the SeaWiFS Project, NASA/Goddard Space Flight Center, and ORBIMAGE.

Projections

Michigan's climate is expected to grow warmer and more variable, with increasing drought stress in late summer.[8] Winters are expected to warm faster than other seasons. Rainfall shows an increase in spring, but a possible decrease in summer. However, precipitation projections vary considerably among models and across regions. Warmer summer temperatures and less rainfall can lead to more severe droughts. Increased CO_2 levels tend to boost forest productivity but this effect may be limited by water availability and other environmental conditions. Growing seasons are expected to continue to lengthen. Table 1 highlights some of the projected climate-related impacts for Michigan forests.[9]

Models

Models based from a variety of sources are used to help predict future forest changes. Models are also useful to determine how different variables interact and which variables may be more important when answering a particular question. Model development and interpretation is complicated. A single tree species or forest type may react differently according to different models or climate inputs.

Effects on more complex climate-driven factors are less certain (wildfire, invasive species), but we have greater confidence in situations where multiple model projections agree and are reinforced by manager expertise.

Table 1. Projected Impacts to Forest Drivers and Stressors

Projected Change (Confidence statements in parentheses)	**Explanation**
Temperatures will increase (robust evidence, high agreement)	*All global climate models project that temperatures will increase with continued increases in atmospheric greenhouse gas concentrations.*
Winter processes will change (robust evidence, high agreement)	*All evidence agrees that temperatures will increase across the Upper Midwest, particularly in winter, leading to changes in snowfall, soil frost, and other winter processes.*
Growing seasons will get longer (robust evidence, high agreement)	*There is a strong agreement that projected temperature increases will lead to longer growing seasons in Michigan.*
Amount & timing of precipitation will change (medium evidence, high agreement)	*All global climate models agree that there will be changes in the precipitation patterns.*
Intense precipitation events will continue to become more frequent (medium evidence, high agreement)	*There is general agreement that the number of heavy precipitation events will continue to increase in the Midwest. This may lead to more damages from flooding and soil erosion.*
Droughts will increase in duration and area (limited evidence, low agreement)	*A study using multiple climate models indicates that drought may increase in extent and area, and an episodic precipitation regime could mean longer dry periods between events.*
Soil moisture patterns will change (medium evidence, high agreement) with drier soil conditions later in the growing season (medium evidence, medium agreement).	*Studies show that climate change will have impacts on soil moisture, but there is disagreement among climate and impact models on how soil moisture will change during the growing season.*
Climate conditions will increase fire risks by the end of the century (medium evidence, medium agreement)	*National and global studies agree that wildfire risk will increase in the region, but few studies have specifically looked at wildfire potential in the Midwest.*
Many invasive species, insect pests, and pathogens will increase or become more damaging (limited evidence, high agreement)	*Evidence indicates that an increase in temperature and greater moisture stress will lead to increases in these threats, but research to date has examined few species.*
Boreal species will face increasing stress from climate change (medium evidence, high agreement)	*Impact models agree that boreal or northern species will experience reduced suitable habitat and biomass across Michigan, and that they may be less able to take advantage of longer growing seasons and warmer temperatures than temperate species.*
Southern species will be favored by climate change (medium evidence, high agreement).	*Impact models agree that suitable habitat and biomass will increase for many temperate species across Michigan, and that longer growing seasons and warmer temperatures will lead to productivity increases for temperate species.*
Forest communities will change across the landscape (limited evidence, high agreement).	*Few models have examined how communities may change, but species-level model results and ecological principles suggest that current forest systems may change in composition and range.*
Forest productivity will increase across the assessment area (medium evidence, medium agreement).	*Some model projections and other evidence support modest productivity increases for forests across Michigan, although there is uncertainty about the effects of CO_2 fertilization. It is expected that productivity will be reduced in localized areas.*

1: National Climatic Data Center, www.ncdc.noaa.gov/cag/
2- 4: Handler et al. 2014. Michigan Forest Ecosystem Vulnerability Assessment and Synthesis. GTR-NRS-129. www.nrs.fs.fed.us/pubs/45688
5: Fisichelli, Nicholas et al. 2013. Temperate Tree Expansion into Adjacent Boreal Forest Patches Facilitated by Warmer Temperatures. Ecography 36: 001-010.
6: Handler et al. 2014.
7: Lenarz et al. 2009. Temperature Mediated Moose Survival in Northeastern Minnesota. Journal of Wildlife Mgmt, 73(4): 503-510.
8-9: Handler et al. 2014.

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Forest Vulnerability

Climate change will affect different tree species and forest types in different ways. Forest impact models can be combined with manager expertise to assess which species and forest types are at risk and which may benefit from projected changes.

The Earth's climate is changing. Many trends have been tracked, some reaching back tens of thousands of years. Trees and forests are sensitive to a range of environmental conditions, including the climate. In addition to climate, there are other factors to which forests will respond, such as human activities and management, biological relationships, and invasive pests. All of this creates a dynamic within which forests will grow and change.

Scientists have built a variety of tools to help understand complex ecological relationships and how forests might look decades into the future. These tools have evolved with computer technology and a growing body of knowledge. Much of what is included in this bulletin is based on these predictions. Additionally, an increasing body of research investigating empirical, on the ground, change will help refine predictions over time.

For example, a tool used to estimate changes in suitable habitat for tree species is called the "Tree Atlas."[1] Tree Atlas uses climate models to assess future habitat suitability for individual species. Whether or not tree species will follow these patterns is a different question because human choices and other pressures also exert significant influence on forest distribution. Exotic pests and diseases will likely be game-changers for some species, but the Tree Atlas doesn't include these kinds of variables.

In another 50-100 years, climate in the upper Great Lakes is expected to resemble modern-day Arkansas and Missouri.[2] How might Michigan's forests respond to those changes? Boreal tree species are expected to decline. Oaks, hickories, red maple, and white pine are expected to do well. Table 1 lists species that are projected to gain or lose suitable habitat in northern Michigan, and table 2 shows results for the state's most common tree species.[3] In addition to "winners" and "losers," there are tree species currently outside Michigan that will gain new habitat, and species where different models show mixed results.

Vulnerability to Climate Change

"Adaptive capacity" is the ability of a tree species or forest to tolerate stress. Forests with reduced diversity or narrow ecological requirements typically have less adaptive capacity, and are at greater risk to changing conditions. Forests more tolerant of disturbance or with higher diversity will likely be better able to tolerate future stress and change.

"Potential impacts" is a combination of a species' exposure to changes as well as their sensitivity to those changes.

"Vulnerability" is a combination of adaptive capacity and potential impacts.

Forest Vulnerability

Tree species tend to grow with common associations called forest types, forest systems, or natural communities. As the climate changes, forest composition, structure, and function will evolve. There will not likely be a simple direct relationship between climate and forest condition because climate is not the only set of factors influencing forests, and climate will affect different forests in different ways.

Tree species with aggressive dispersal strategies will likely occupy new habitat more quickly than other tree species. Highly fragmented landscapes will be a barrier to natural tree species migration. Planting programs may assist migration of future-adapted species, but would likely be very costly across a large area. As of 2014, there is little evidence of tree species migration tied to climate change.[4]

In the Lake States, there is current research examining this issue.[5] As more information becomes available and forest responses become clearer, assessments will be updated. As scientists learn more about how forests change, foresters will be better able to employ management practices to adapt to those changes.

Table 2. Suitable habitat projections for Michigan's most common tree species (67% of forest volume)[3]

Tree Species	Suitable habitat projections
Sugar maple	Mixed Results
Red maple	Mixed Results
Northern white-cedar	Loser
Red pine	Mixed Results
Northern red oak	Mixed Results
Quaking aspen	Loser
Eastern white pine	Mixed Results
Bigtooth aspen	Mixed Results
Eastern hemlock	Mixed Results
Black cherry	Mixed Results

Table 1. Projected changes in suitable habitat for selected tree species in northern Michigan[3]

"Winners"			Mixed Results	"Losers"	
American elm	Blackgum	Shagbark hickory	American basswood	Balsam fir	Paper birch
Ironwood	Eastern redcedar	Silver maple	Bur oak	Balsam poplar	Quaking aspen
Black locust	Flowering dogwood	Slippery elm	Eastern hemlock	Black spruce	Tamarack
Black oak	Honeylocust	Sycamore	Red pine	Jack pine	White spruce
Black walnut	Sassafras	White ash	Sugar maple	Mountain maple	
Black willow	Scarlet oak	White oak	Yellow birch	Northern white-cedar	

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Vulnerability by Forest System

In a recent assessment, researchers and managers from a variety of organizations looked at the vulnerability of northern Michigan's forest systems to climate change (Table 3).[6] The following summaries are from that assessment. The western UP is covered in a companion assessment with northern Wisconsin.[7]

Upland spruce-fir forests are highly vulnerable to climate change (medium to high evidence, medium to high agreement). The boreal species within upland spruce-fir forests are not projected to tolerate warmer temperatures, increased competition from other forest types, and more active forest pests. In Michigan, these forests are generally restricted to lake-effect areas on the landscape.

Jack pine has a high to moderate vulnerability assessment (medium evidence, high to medium agreement). Impact models project declines in suitable habitat and biomass for jack pine, as a species, and pests and diseases may become more damaging under climate change. A high tolerance for disturbance and the current management emphasis increases the adaptive capacity of jack pine types.

Red and white pine forests have a moderate to high vulnerability status (medium to limited evidence, medium agreement). The potential for greater pest and disease activity is a major threat to red pine and white pine forests, along with the potential for interactions among stressors. Tolerance for drought and disturbance increases the adaptive capacity of these forests, and the future fire regime is a primary uncertainty.

Swamp conifer vulnerability to climate change is rated high to moderate (medium evidence, medium agreement). Lowland conifer types have limited tolerance to changes in water tables. Additionally, the dominant species (cedar, black spruce, tamarack) in these forests are expected to decline under a range of climate futures. Low agreement on future precipitation and groundwater levels are the primary uncertainties for these systems.

Aspen forests are moderately vulnerable to climate change (medium evidence, medium agreement). Models project declines for aspen in northern Michigan and multiple stressors could interact under climate change, particularly drought and pests. These forests are a management priority, however, and are adapted to disturbance and exist on a wide range of sites.

Northern hardwoods, Michigan's most common forest type, are moderately vulnerable (medium evidence, medium agreement). Climate change may intensify several major stressors for northern hardwoods, such as drought, invasive species, and forest pests. Higher species diversity may increase resilience to future change. Uncertainty regarding future moisture regimes and potential interactions between stressors limit the confidence in this conclusion.

Swamp hardwoods, including the different lowland and riparian forest types, have moderate vulnerability (medium evidence, low to medium agreement). Altered hydrology may amplify the effects of pests and invasive species. Higher diversity and the presence of more southern species raise the adaptability of these forests. Future precipitation regimes are the primary uncertainty.

Oak associations have low-moderate vulnerability (medium evidence, medium agreement). Oaks are more tolerant of drought and warmer temperatures. White and black oak, which are projected to increase, already occur in the northern Lower Peninsula. Oak types are less common in the Upper Peninsula.

Barrens have low-moderate vulnerability to climate change (limited-medium evidence, medium agreement). They exist on dry sites with a sparse tree canopy. Barrens are mostly grasslands associated with jack pine, oaks, and a few other species. They may be well-adapted to warmer temperatures and episodic precipitation. More wildfires may benefit this system but an excessive amount could eliminate the tree component.

Table 3. Vulnerability summaries by forest system[6]

Forest System	Vulnerability	Evidence	Agreement
Upland spruce-fir	High	Medium-High	Medium-High
Jack pine	High-Moderate	Medium	Medium-High
Red pine/ white pine	High-Moderate	Limited-Medium	Medium
Lowland conifers	High-Moderate	Medium	Medium
Aspen-birch	Moderate	Medium	Medium
Northern hardwoods	Moderate	Medium	Medium
Lowland/ riparian hardwoods	Moderate	Medium	Low-Medium
Oak associations	Low-Moderate	Medium	Medium
Barrens	Low-Moderate	Limited-Medium	Medium

1: Climate Change Tree Atlas, http://www.fs.fed.us/nrs/atlas/
2-3: Handler et al. 2014. Michigan Forest Ecosystem Vulnerability Assessment and Synthesis. GTR-NRS-129. www.nrs.fs.fed.us/pubs/45688
4: Zhu, Kai et al. 2012. Failure to Migrate: Lack of Tree Range Expansion in Response to Climate Change. Global Change Biology. 18(3): 1042-1052.
5: Fisichelli, Nicholas et al. 2013. Temperate Tree Expansion into Adjacent Boreal Forest Patches Facilitated by Warmer Temperatures. Ecography 36: 001-010.
6: Handler et al. 2014.
7: Janowiak et al. 2014. Northern Wisconsin and western Upper Peninsula Ecosystem Vulnerability Assessment and Synthesis. GTR-NRS-136. www.forestadaptation.org/WI-MI-FEVAS.

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Adaptation Strategies and Approaches

Foresters and landowners will respond to climate change in different ways, based on their judgment of risks and opportunities. A range of adaptation actions can be taken, which can be selected based on management objectives.

The Earth's climate is changing. Many trends have been tracked, some reaching back tens of thousands of years. Trees and forests are sensitive to a range of environmental conditions, including the climate. In addition to climate, there are other factors to which forests respond, such as human activities and management, biological relationships, and invasive pests. All of this creates a dynamic within which forests grow and change.

While there is no doubt among the scientific community that the climate is changing, the ecological response of Michigan's forests is more uncertain (see other bulletins in this series).

Foresters and landowners will naturally have different perspectives on how to judge climate change risks and opportunities. They will also have different institutional constraints when it comes to taking action. Even so, it is prudent for foresters to consider what they can do in order to help forests adapt to climate change. In many cases, preparing for climate change offers "win-win" opportunities because many adaptation actions are already fundamental practices of good forestry. Also, many adaptation actions can address forest stressors that foresters are already used to considering, such as drought and forest pests.

Swanston & Janowiak (2016) articulate a series of forest management strategies and approaches in light of a changing climate (Table 1).[1] These ideas are part of spectrum of adaptation choices (Figure 1) which lead to site-specific tactics, or management practices. The following set of adaptation strategies and approaches can generate ideas for on-the-ground practices. This list is proposed as a "menu" of possible actions – the idea is to pick and choose the approaches that are most suitable to a particular management goal and forest type. Not all items on the menu will work together, although they can be applied in various combinations across a landscape or project area. Also, foresters may generate additional ideas that can be added to the menu.

Table 1. Forest Adaptation Strategies and Approaches[1]

Strategy 1: Sustain fundamental ecological functions.
1.1. Reduce impacts to soils and nutrient cycling.
1.2. Maintain or restore hydrology.
1.3. Maintain or restore riparian areas.
1.4. Reduce competition for moisture, nutrients, and light.
1.5. Restore or maintain fire in fire-adapted ecosystems.

Strategy 2: Reduce the impact of biological stressors.
2.1. Maintain/improve the ability of forests to resist pests & pathogens.
2.2. Prevent the introduction and establishment of invasive plant species and remove existing invasive species.
2.3. Manage herbivory to promote regeneration of desired species.

Strategy 3: Reduce the risk and impacts of severe disturbances.
3.1. Alter forest structure or composition to reduce risk or severity of wildfire.
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.
3.4. Promptly revegetate sites after disturbance.

Strategy 4: Maintain or create refugia.
4.1. Prioritize and maintain unique sites.
4.2. Prioritize and maintain 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 species.
5.3. Retain biological legacies.
5.4. Establish reserves to maintain 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. Reduce landscape fragmentation.
7.2. Maintain and create habitat corridors through reforestation or restoration.

Strategy 8: Maintain and enhance genetic diversity.
8.1. Use seeds, germplasm, and other genetic material from across a greater geographic range.
8.2. Favor existing genotypes better adapted to future conditions.

Strategy 9: Facilitate community adjustments through species transitions.
9.1. Favor or restore native species that are expected to be adapted to future conditions.
9.2. Establish or encourage new mixes of native species.
9.3. Guide species composition at early stages of stand development.
9.4. Protect future-adapted seedlings and saplings.
9.5. Disfavor species that are distinctly maladapted.
9.6. Manage for species and genotypes with wide moisture and temperature tolerances.
9.7. Introduce species that are expected to be adapted to future conditions.
9.8. Move at-risk species to locations that are expected to provide future habitat.

Strategy 10: Realign ecosystems after disturbance.
10.1 Promptly revegetate sites after disturbance.
10.2. Allow for areas of natural regeneration to test for future-adapted species.
10.3. Realign significantly disrupted ecosystems to meet expected future conditions.

To better understand how each of the approaches in Table 1 might be relevant to risks associated with climate change, review the "Vulnerability Assessments" that have been prepared for Michigan's Northern Lower Peninsula / Eastern Upper Peninsula (Handler et al. 2014)[2] or Northern Wisconsin / Western Upper Peninsula of Michigan (Janowiak et al. 2014).[3] For example, measures to protect against severe weather become even more important when the frequency and severity of these events are expected to increase.

Swanston & Janowiak (2016) also provide a workbook process to help foresters and landowners consider climate change. This workbook process starts with identifying management objectives, and includes separate steps for considering climate change risks and opportunities and selecting adaptation actions from the menu that will help achieve management objectives.

Implementing drastic adaptation actions, such as long-distance assisted migration, may be warranted only in limited situations. However, managing forests to increase basic ecological strengths (such as forest resilience, species diversity, and tree vigor) is good forestry under any circumstances.

Monitoring forest conditions over the long-term will be essential to adapting management to meet future challenges, not only from climate change, but also the wide array of socio-economic-cultural trends that are currently underway (e.g. parcelization, exotic pests, loss of forest industry, emerging technologies, etc.).

Figure 1. A continuum of adaptation actions is available to address needs at appropriate scales and levels of management (top). The lower boxes provide examples of each level of action. Numbers in parentheses refer to adaptation strategies and approaches from Table 1. (Modified from Swanston and Janowiak 2016).

CONCEPT → ACTION

OPTIONS	**STRATEGIES**	**APPROACHES**	**TACTICS**
Foundational adaptation concepts *(after Millar et al. 2007)*	Broad adaptation responses that consider ecological conditions and overarching management goals	More detailed adaptation responses with consideration of site conditions and management objectives	Prescriptive actions designed for specific site conditions and management objectives
RESISTANCE Buffer or protect from change.	Maintain or create refugia.	Prioritize and maintain sensitive or at-risk species or communities.	Reroute roads or trails away from at-risk communities.
RESILIENCE Promote the return to normal conditions after a disturbance.	Reduce the risk and long-term impacts of severe disturbances.	Alter structure or composition to reduce risk or severity of fire.	Restore fire in oak forests to reduce surface fuel and promote fire- and heat-tolerant species.
TRANSITION Actively facilitate or accommodate change.	Facilitate community adjustments through species transitions.	Introduce species that are expected to be adapted to future conditions.	Plant swamp white oak to replace ash lost to decline resulting from emerald ash borer.

1: Swanston, C.W. and M.K. Janowiak (editors). 2016. Forest Adaptation Resources: Climate Change Tools and Approaches for Land Managers (2nd Edition). GTR-NRS-XX. www.forestadaptation.org/far

2: Handler et al. 2014. Michigan Forest Ecosystem Vulnerability Assessment and Synthesis. GTR-NRS-129. www.nrs.fs.fed.us/pubs/45688

3: Janowiak et al. 2014. Northern Wisconsin and western Upper Peninsula Ecosystem Vulnerability Assessment and Synthesis. GTR-NRS-136. www.forestadaptation.org/WI-MI-FEVAS.

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Adaptive Management

Many of the management practices that are already "smart forestry" can have valuable win-win benefits for climate change adaptation.

The Earth's climate is changing. Many trends have been tracked, some reaching back tens of thousands of years. Trees and forests are sensitive to a range of environmental conditions, including the climate. In addition to climate, there are other factors to which forests respond, such as human activities and management, biological relationships, and invasive pests. All of this creates a dynamic within which forests grow and change.

What might a forester do to embrace the changing environment and maintain productive forests? Interactions between forests and climate change will occur over decades, so management practices and landowner decisions will need to evolve with time. In terms of the next few years, there is probably not anything drastic that must be done differently. Employing current forest management practices to enhance forest diversity and health will increase resiliency and best position forests for the future, with or without climate change. Active forestry remains the best option.

What are some of the practices to best prepare forests for the future? Forest managers and owners have options that can be exercised in current management plans.

Increase species diversity, where appropriate. Each forest type has an inherent amount of species diversity. For example, jack pine forests have fewer species than northern hardwoods. Maximizing the natural diversity potential of a given forest type can help forests be resilient to both current and future pressures and provide more options for the future.[1]

Harvest operations in a mixed pine stand. Photo by US Forest Service, Huron-Manistee National Forest.

Encourage diverse stand structures and age classes to reduce risk and provide future options. Thinning may become increasingly important in some forest types as climate change increases the likelihood of summer drought stress. Variable thinning can help create a diversity of age classes and encourage a wider range of species, which is a way of reducing risk.

Northern hardwoods is Michigan's most common forest type. **Using group selection**, rather than single-tree selection, can encourage a wider tree species mix and diverse stand structure. Current research suggests gaps should be 50-100 feet in diameter. Gap shape can vary. Gaps can be placed near less common tree species currently present in the stand, such as yellow birch, white pine, red oak, or hemlock.

Monitor for invasive exotic plants, which are a serious and increasing problem. Consider herbicides, among other control techniques, to eradicate these species to the extent possible. These problem plants often work in concert with exotic animals (e.g. earthworms) and native animals (e.g. deer) to low-diversity ecological states. Impaired communities may be less resilient to the effects of climate change.

White-tailed deer fawn. Photo by Christopher Hoving, Michigan Department of Natural Resources.

Excessive deer browsing plays an important role in this matrix. White-tailed deer are expected to be favored by milder winters. Deer are already a major factor in forest regeneration failure[2] and work in concert with other species (native and exotic) to push forest systems to less productive states. Hunting is currently insufficient to attain deer population targets, especially on private forestland. Different strategies may be required to control burgeoning populations.[3]

Watch for the presence of damaging exotic insects and forest pathogens. New threats will continue to occur. Incorporate response alternatives into forest management plans. A few impending threats to Michigan forests include Asian long-horned beetle, hemlock and balsam woolly adelgid, thousand cankers disease, and oak wilt.[4]

Carefully evaluate forest regeneration (trees and understory plants) and note changes. For example, red maple is now regenerating in boreal forests northern Minnesota.[5] In Michigan, sugar maple regeneration on more marginal sites may decline if earthworm activity reduces the humus layer.[6] Most forest management practices are designed to provide environmental conditions that promote regeneration. However, regeneration success can often be diminished (or eliminated) due to other factors.

Consider assisted migration or managed relocation when appropriate. These are terms for intentionally introducing tree species or seed stock from areas that are currently experience climate conditions expected in the future. Trees with naturally short-range seed dispersal strategies may not be able to naturally migrate fast enough to take advantage of appropriate new habitats created by warming conditions. Fragmented forests and other physical barriers can prevent natural migration. Humans can encourage tree migration by planting, although landscape-level projects would be very costly and risks need to be considered.

When planting is desired, **using containerized stock in the fall** may become preferable to bare-root planting in the spring, currently the traditional planting season. Newly established seedlings in the spring often die from summer droughts, which are expected to become more frequent and severe. Containerized stock come with a soil plug and may become more acclimatized to their new location prior to summer dry periods.

Consider shortening rotation lengths for some at-risk, even-aged species. A "rotation" is the number of years between stand establishment and final harvest. Aspen, jack pine, and spruce-fir forest types are harvested and regenerated through clearcutting, based on their natural disturbance regimes. As mid-century approaches, rotations may need to be shortened if climate change leads to a loss of productivity. At that time, converting the stands to more suitable forest types may need to be considered.

Management for savannas, prairies, and barrens may become more appropriate for some places on the landscape. Photo by Heather Keough, Huron-Manistee National Forest.

Establish plantations of appropriately-adapted species, when needed to provide certain forest products or habitat conditions. Breeding programs typically require decades to develop stock suited to particular conditions. The role of short-rotation, intensive-culture energy plantations of hybrid poplar and hybrid willow may become more desirable and financially feasible.

Monitor forests and the success of forest management practices. Forests are dynamic ecological systems that will respond to climate change in both predictable and unpredictable ways. Forest responses will not be uniform across the region or landscape. It will be important to work with the research community to help identify and describe forest change.

The **desired future conditions** of current forest management, for the most part, should be current forest types that are best suited to the site. However, novel successional pathways or new species mixes may need to be considered. Forest management practices may need to be re-considered to accommodate alternate goals and objectives. For example, on drier and marginal sites, maintaining closed-canopy forest cover may not be an option, even with planting programs. These sites may need to be managed for substantially less forest cover.

1: Swanston, C.W. and M.K. Janowiak (editors). 2012. Forest Adaptation Resources: Climate Change Tools and Approaches for Land Managers. GTR-NRS-87. www.treesearch.fs.fed.us/pubs/40543
2: Cote, Steeve et al. 2004. Ecological Impacts of Deer Overabundance. Annu. Rev. Ecol. Evol. Syst. 35:113-47.
3: Vercauteren, Kurt et al. 2011. Regulated Commercial Harvest to Manage Overabundant White-tailed Deer: An Idea to Consider? Wildlife Society Bulletin, 35(3): 185-194.
4: Handler et al. 2014. Michigan Forest Ecosystem Vulnerability Assessment and Synthesis. GTR-NRS-129. www.nrs.fs.fed.us/pubs/45688
5: Fisichelli, Nicholas et al. 2013. Temperate Tree Expansion into Adjacent Boreal Forest Patches Facilitated by Warmer Temperatures. Ecography 36: 001-010.
6: University of Minnesota, Natural Resources Research Institute. 2013. Forest Ecology and Worms. www.nrri.umn.edu/worms/forest/soil.html

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Forest Adaptation Glossary

New terms are used in the discussions of climate change and forest adaptation.[1,2] Having a working vocabulary helps to better understand many of the concepts and how they relate to each other.

Adaptation: *Taking action to prepare for current and expected impacts of climate change.*

Adaptive Capacity: *The general ability of institutions, systems, and individuals to moderate the risks of climate change, or to realize benefits, through changes in their characteristics or behavior. Adaptive capacity can be an inherent property (e.g. natural ecosystems) or it could have been developed (e.g. community wildfire protection plan).*

Agreement: *The extent to which evidence is consistent in support of a vulnerability statement or rating (Figure 1).*

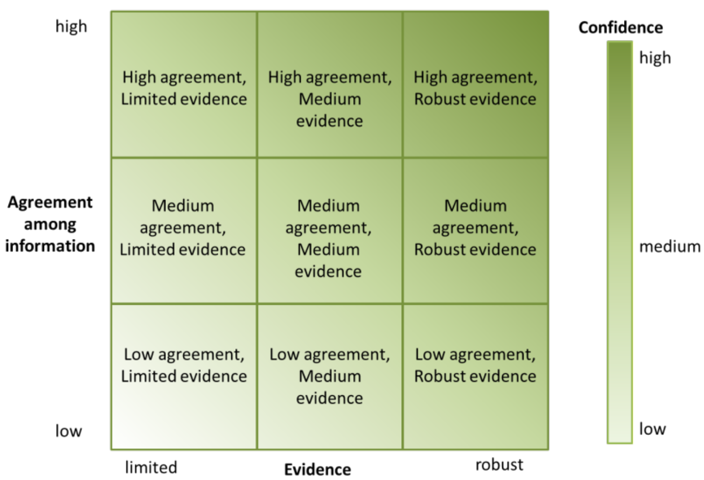

Figure 1: Agreement, Evidence, and Confidence. From Handler et al. 2014.

Alternate Ecological State: *A change in ecological characteristics of a biological system, often triggered by invasive stresses of either native or exotic species, that leads to a different set of long-term ecological conditions. These states are usually less diverse, less productive, and generate fewer (or lower quality) ecological services and/or products for human consumption.*

Asynchrony: *When events that normally occur in a particular sequence, or together, no longer do so. For example, earlier spring flower break may come earlier than the emergence of insect pollinators, resulting in lowered plant fertilization rates.*

Cascading Impacts: *Multiple changes in composition, structure, and/or function of an ecological system (e.g. forest) triggered by a new element or combination of elements. Cascading impacts can lead to alternate ecological states.*

Climate: *The mean and variability atmospheric trends that persist for an extended period, typically decades or longer. Climate is different than weather, which is a short-term phenomenon.*

Climate Change: *A change in the state of the climate that can be identified (by using statistical tests) by changes in the mean and/or the variability of its properties over an extended period. Climate change can occur due to natural processes and to persistent anthropogenic change in the composition of the atmosphere or in land use.*

CO_2 Fertilization: *The increase in plant uptake of carbon dioxide (CO_2) through photosynthesis in response to higher concentrations of atmospheric CO_2.*

Confidence: *A qualitative assessment of uncertainty as determined through evaluation of evidence and agreement. This definition is different than that which is commonly used.*

Disturbance: *Stresses and destructive agents (e.g. pests, pathogens, fire, storms, timber harvest, etc.) that cause changes in forest composition, structure, or function. Disturbance can be natural, human-caused, or a combination of both.*

Driver: *A natural or human-caused factor that determines the identity of an ecosystem (e.g. acidic peat soils for a black spruce swamp).*

Downscaling: *Statistical methods to obtain higher-resolution climate or climate change information from coarse-resolution general circulation models (GCMs). GCMs are reliable over large areas of the earth's surface. Downscaled models are more specific to smaller regions.*

Error: *A statistical measure that represents an estimate from a known quantity. The scientific definition is different than more common definitions.*

Evidence: *Research-based information, sometimes expert judgment, used to determine a level of confidence in a vulnerability statement or rating.*

Exposure: *The degree to which a species or system experiences a stressor or set of stressors. Combined with sensitivity to assess the potential impact of that stressor or set of stressors. Exposure is like the length of time a person spends in direct sunlight, and greater exposure make them more likely to become sunburned.*

General Circulation Model (GCM): *Numerical representation of the climate system based on the physical, chemical, and biological properties of its components, their interactions and feedback processes, and accounting for all or some of its known properties. GCMs are often tested on their ability to reproduce known historical data before making projections into the future.*

Impact: *The direct and indirect consequences of climate change on systems (natural and human), particularly those that would occur without adaptation. Impacts are a combination of exposure and sensitivity.*

Impact Model: *A model that projects potential impacts of climate change on a particular species or system (natural or human). Impact models should be used as tools to better understand the possible effects of climate change, not as concrete predictions of the future.*

Novel Species Mix: *New plant and animal associations, caused by stressors such as climate change, that do not normally occur.*

Novel Successional Pathways: *Changes in ecosystems, caused by stressors such as climate change, from one forest type to another forest type. These changes would be different from what might be expected under ordinary conditions.*

Phenology: *The study of the timing of natural events (e.g. dates that migrating birds return, flowering dates, ice on / ice off).*

Risk: *The degree to which a species or system (natural or human) is vulnerable to new conditions, such as climate change. The amount of risk will vary considerably based on a variety of factors. It is important to consider risk when weighing management actions for adaptation.*

Response Diversity: *The number of ways a species or system (natural or human) might change when a new set of conditions are introduced.*

Projection: *The potential change in a set of quantities, often computed with the help of a model. Projections differ from predictions in that they employ stated assumptions (that can be modified) about socio-economics, technology, industry trends, and other conditions.*

Resilience: *The ability of a species or system (natural or human) to withstand a given level of impacts or stressors and still return to a prior state. Resilience is related to adaptive capacity.*

Sensitivity: *The degree to which a species or system will experience an impact when exposed to a stressor. Combined with exposure to assess the potential impact. For example, fair-skinned people have greater sensitivity to direct sunlight and are more likely to become sunburned than dark-skinned people.*

Stressor: *An agent, condition, change in condition, or other stimulus that causes stress to an organism or ecological system.*

Uncertainty: *The statistical expression of the degree to which a value is unknown. Uncertainty can result from inherent complexity, lack of information, or from disagreement about what is known or even knowable. It may have many types of sources, from quantifiable errors in the data to ambiguously defined concepts or terminology, or uncertain projections of human behavior. Uncertainly can be described using quantitative measure or by qualitative statements.*

Vulnerability: *A term to describe differences among species or systems (natural or human) in their response to climate change. A combination of exposure, sensitivity, and adaptive capacity (Figure 2).*

Weather: *The state of the atmosphere at a given time and place, with respect to variables such as temperature, moisture, wind, and barometric pressure. Weather is not the same as climate.*

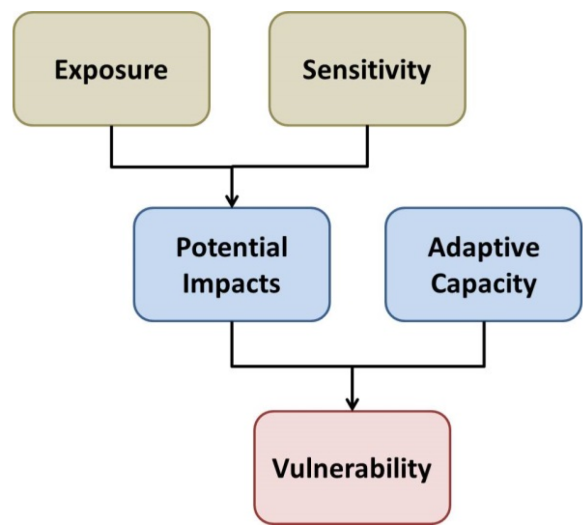

Figure 2: The elements of Vulnerability: Exposure, Sensitivity, Potential Impacts, and Adaptive Capacity. From Handler et al. 2014.

1: Swanston, C.W. and M.K. Janowiak (editors). 2012. Forest Adaptation Resources: Climate Change Tools and Approaches for Land Managers. GTR-NRS-87. www.treesearch.fs.fed.us/pubs/40543

2: Handler et al. 2014. Michigan Forest Ecosystem Vulnerability Assessment and Synthesis. GTR-NRS-129. www.nrs.fs.fed.us/pubs/45688

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