Future Forests: A Framework for Adaptive Management at Marsh-Billings-Rockefeller National Historical Park

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Abstract

Natural resource managers are faced with significant challenges as they seek to ensure that forests continue to provide critical goods, services, and functions. Increasingly, managers must continually accommodate shifting societal demands on forests, increased threats from damaging insects, diseases, and invasive species, and a changing climate. These forces of change, referred to by many as global environmental change, represent one of the greatest challenges facing forest resource managers today. The uncertainty and variability around the potential future impacts on forest systems, compels managers to continually adapt to change, implement alternative management approaches, and regularly evaluate the outcomes of our management decisions. This report applies an adaptive management framework, originally developed by the US Forest Service, to assist the Marsh-Billings-Rockefeller National Historical Park in planning for future forest management. In this report we provide a road map for resource managers at MABI to mitigate and adapt to the challenges posed by a changing climate and a host of other stressors, to help ensure that the forest remains productive and resilient into the future. In addition, this report utilizes forest landscape simulation modeling techniques to evaluate the potential long-term impacts of a range alternative management approaches and climate change scenarios on future forest conditions.

Table of contents

Figures

Tables

Introduction

Forest managers are faced with many challenges as they seek to achieve multiple objectives and ensure forest systems continue to deliver the goods and services we have come to rely on. Increasingly, forest managers have to deal with new or novel stressors such as pests and pathogens, invasive species, and a changing climate. The uncertainty around how these stressors will impact future forest structure and function has led managers to re-evaluate management decisions and tactics. We have developed a detailed step-by-step adaptive management framework to address these challenges and to assist the resource managers at Marsh-Billings-Rockefeller National Historical Park (MABI) in planning for the future. We also utilize computer modeling techniques to explore and evaluate a range climate change scenarios and management approaches on future forest composition at MABI.

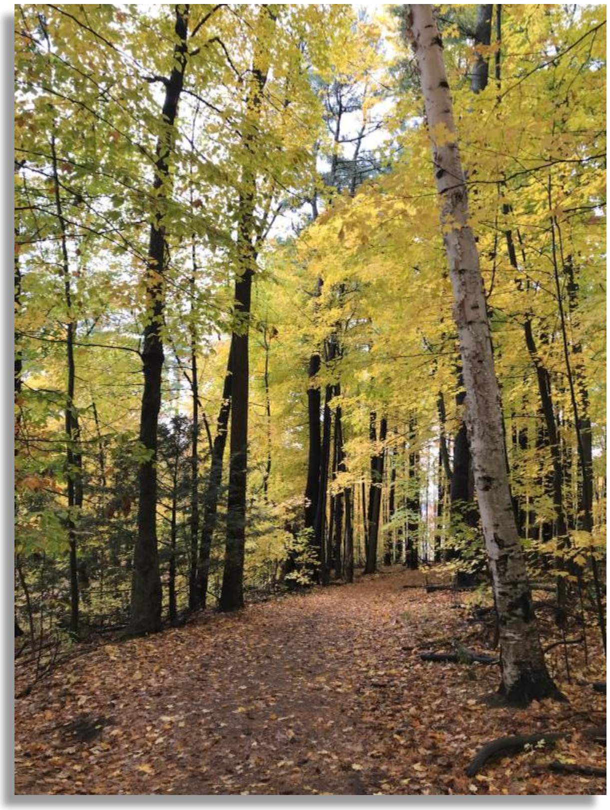
The future of our forests remains increasingly uncertain as our expected climate patterns shift and new stressors interact with the forest in novel ways. However, the framework presented here provides a structured approach for dealing with uncertainty and provides a set tools for addressing the specific challenges facing the forests at MABI.

In the first chapter of this report we highlight the long history of forest management at MABI and provide additional context for the development of a structured adaptive management framework. In Chapter 2, we provide an introduction to the principles of adaptive management and present the framework applied at MABI. Chapter 3 outlines the over-arching goals and objectives for the management of the forest resources at MABI. In chapter 4, a vulnerability assessment of each forest type at MABI is presented. Chapter 5 evaluates current management goals based on the vulnerabilities identified in Chapter 4. Chapter 6 explores potential alternative and adaptive management strategies and tactics that can be applied within the different forest types found at MABI. The alternative management tactics are summarized in a management *MENU* which can be utilized in the future to address pressing management challenges.

In chapter 7, a framework for the continued monitoring of management outcomes is presented. In Chapter 8, computer modeling techniques are used to explore a range of projected long-term impacts of three adaptive management regimes under three climate change scenarios.

Chapter 1: Context for adaptive forest management

Marsh-Billings-Rockefeller National Historical Park (MABI) was established by an act of congress in 1992 for the purposes of interpreting the history of conservation and stewardship in America and to recognize the legacies of the Marsh, Billings, and Rockefeller families. MABI serves the public as a living exhibit, which illustrates the evolution of forest stewardship in America and serves as a model for contemporary forest management regionally. As one walks the carriage roads and foot paths at MABI, the history of forest stewardship is on display. From some of the earliest examples of scientific silviculture borrowed from Europe in the nineteenth century, to some of the best examples of contemporary forest management.



MABI is managed with the goal of perpetuating the tradition of sustainable forest management while incorporating a long-term perspective on the changing composition and character of the forest. The long-term management goals for MABI seek to ensure that both the natural and cultural values derived from the forest are sustained while fostering a strong connection to the broader community through civic engagement and demonstration of forest stewardship.

The most recent Forest Management Plan, developed for MABI in November of 2006, established these long-term management goals through an analysis of multiple alternative management scenarios (Marsh-Billings-Rockefeller 2006). The preferred management approach aims to addresses current and shifting ecological conditions while still maintaining the historic elements of the culturally significant landscape.

During the long-term forest management planning process, the need for the future development of an adaptive management framework specific to the forest at MABI was identified. Since the development of the forest management plan in 2006, there has been a continued focus on the integration of adaptive management. Most recently, a vulnerability assessment was developed for the park and a series of workshops on climate change adaptation have been led by the Northern Institute of Applied Climate Science. This report synthesizes and builds upon recent adaptive management planning efforts by developing and applying a framework for continued adaptive forest management. Additionally, this report provides detailed evaluation of alternative adaptive management under multiple climate change scenarios using forest landscape simulation modeling.

Chapter 2: A framework for adaptive management

Adaptive management is a structured decision making process for improving resource management that embraces flexibility in the face of uncertainty and focuses on learning from management outcomes (Williams et al. 2009). Many organizations are now actively incorporating adaptive management principles into their decision making process as a means of managing the increasing uncertainty around the maintenance and enhancement of the goods and services natural systems provide.

The U.S. Forest Service has developed a framework for land managers looking to integrate adaptive management into their planning process (Swanston et al. 2016). This framework is described in detail in the publication "Forest Adaptation Resources: Climate Change Tools and Approaches for Land Managers, 2^{nd} edition" which outlines a systematic and iterative approach that can be easily applied to specific management situations (Swanston et al. 2016). This framework draws upon five major components (Figure 1). First, managers work in partnership with stakeholders to **DEFINE** the area in which they will be working and establish management goals, objectives, and timeframes. Second, an assessment (**ASSESS**) of system vulnerabilities is conducted. Third, the management team **EVALUATE(S)** their management objectives based on the identified vulnerabilities. In the fourth component of the framework, management strategies are **IDENITIFIED and IMPLEMENTED.** The fifth and final component of this adaptation framework highlights means by which implemented management strategies can **MONITORED AND EVALUATED** based on desired outcomes.

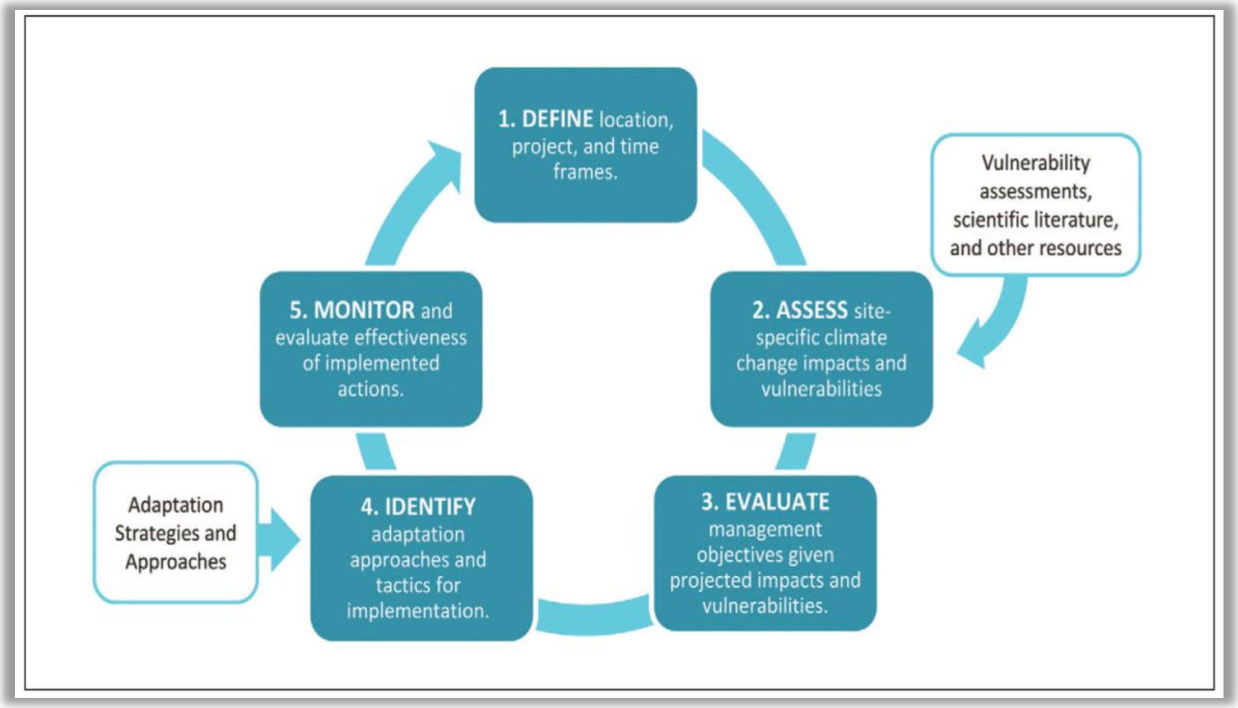


Figure 1: Climate change response/adaptation framework adapted from the "Forest Adaptation Resources: Climate Change Tools and Approaches for Land Managers, 2nd edition."

The key components of this framework were tailored to fit the specific needs of the management team at MABI. In addition, we have developed a plan which incorporates the latest research and understanding on managing for the uncertainty of climate change impacts. This report draws heavily on the findings from recent publications such as the *New England and Northern New York Forest Ecosystem Vulnerability Assessment and Synthesis* (Janowiak et al. 2018) and the *Forest vulnerability to climate change and tree pests at Marsh-Billings-Rockefeller National Historical Park* developed in 2014 (Fisichelli). These two resources provide regional and local analysis of potential impacts to forests and their ability to adapt to these projected changes.

Chapter 3: Define management goals and objectives

The long-term management goals and objectives for forest management at MABI were developed in 2006. Given MABI's unique mission to maintain the significant historical resources while conserving and enhancing other natural and cultural resources, alternative management approaches were analyzed. Ultimately, with input from stakeholders, it was determined that the preferred management scenario would maintain the cultural legacy of forest management on the property while working with ecological change and continuing to apply the best current thinking and practices for forest management. In practice, this approach aims to preserve the valuable cultural resources associated with scenic views of a historic working landscape and also the maintenance of biological legacies of past management. These legacies are experienced throughout MABI in the form of amazing old trees along carriage roads and the towering trees that remain in some of the Park's earliest plantations.

MABI Management Goals

1. Practice and promote the tradition of sustainable forest management
2. Protect and enhance both natural and cultural values present in the forest
3. Preserve historic character of MABI and Forest
4. Continue to provide enjoyable and engaging user experience and recreation opportunities
5. Build community through civic engagement, collaborative stewardship, education, and interpretation
6. Incorporate adaptive management perspectives on managing for changing forest composition and function

Guided by these management goals and annual planning meetings, the forest management team at MABI have developed detailed management objectives and desired future conditions for all the forest stands present within MABI. The process of developing stand-specific management activities will continue using the forest inventory data collected every five years by MABI's consulting forester. The goal of this report is to provide additional resources to the continued development management objectives and evaluation of management implementation.

In order to address both broad scale management objectives and provide specific management recommendations, we have opted to divide MABI into four dominant forest types or *forest systems* (Figure 2). These forest systems encompass multiple stands and provide a basis for identifying current management objectives and desired future conditions. Subsequent chapters will build on this division of the forest into dominant forest systems.

MABI Forest Systems

- Northern Hardwood Forest
- Plantation Forest
- Hemlock-Hardwood Forest
- Culturally and Ecologically significant areas.

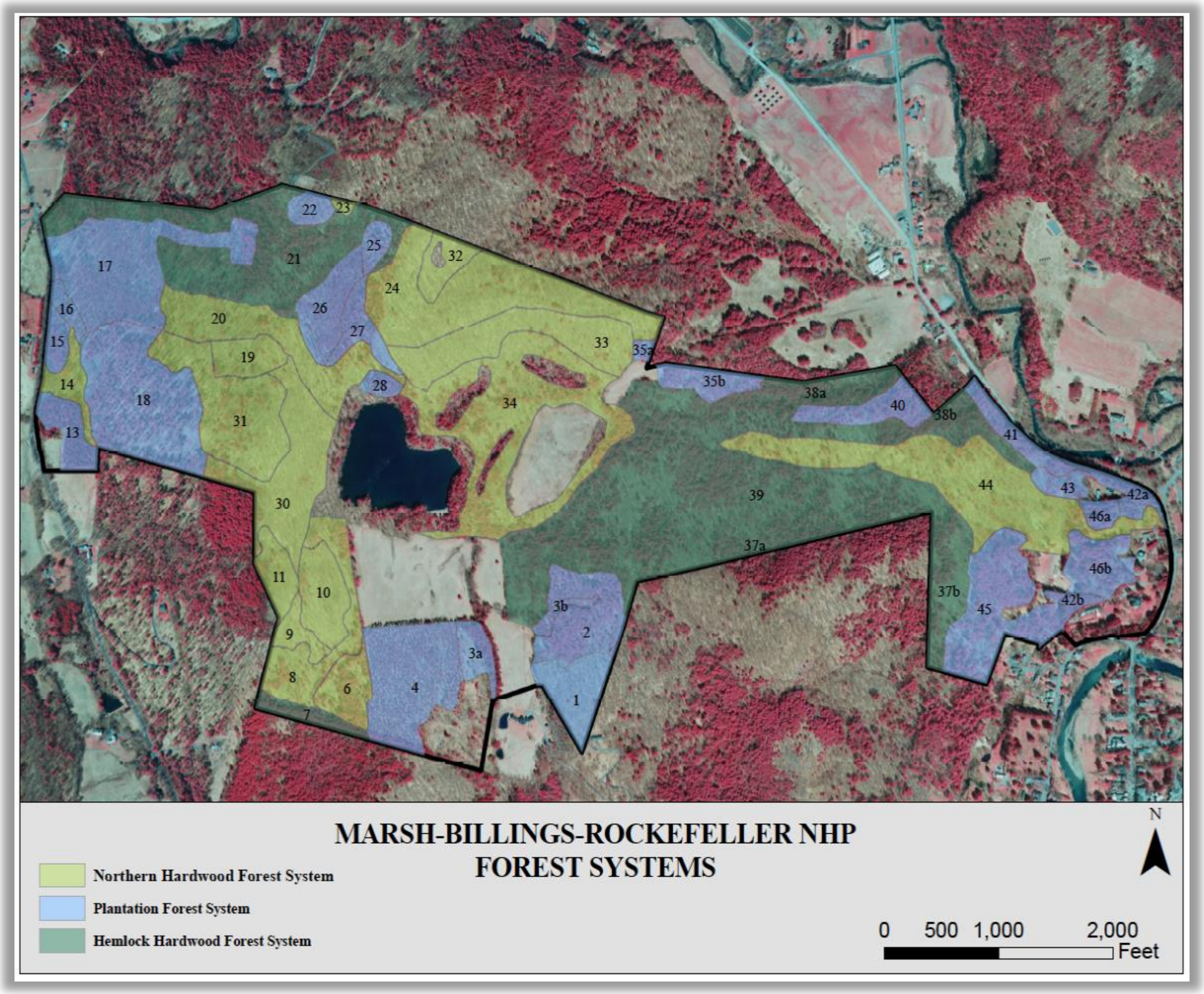


Figure 2: Forest systems of Marsh-Billings-Rockefeller NHP. There three forest systems are shown on the map of MABI and forest stand numbers are also included. Culturally Significant Areas are not identified on the map and are located throughout the property.

Northern Hardwood Forest System

Northern hardwood forest systems are the most dominant forest type in Vermont. The northern hardwood system is similar to the natural community classification of the same name but includes similar natural community types such as *rich northern hardwood* and accommodates some variation in site conditions and forest composition (Thompson, 2015). Northern hardwood systems exist across MABI on a range of soil types and are composed primarily of sugar maple, American beech, and white ash with lesser representation of eastern white pine, eastern hemlock, and yellow birch.

Northern Hardwood systems encompass approximately 165-acres throughout MABI. This forest system established after agricultural fields were abandoned in the late 1800s and is predominantly even-aged as a result. This forest system was historically managed with intermediate treatments (i.e. thinning) which were used as a means of allocating more resources to desirable species of acceptable growing stock in the overstory. Following the development of the 2006 Forest Management Plan, forest management has shifted towards practices that promote a healthy and more diverse forest both compositionally and structurally. Uneven-aged management approaches such single tree and group selection have been prescribed in the past ten years along with the continued application of intermediate treatments.

Each individual stand within the Northern Hardwood Forest system have specific desired future conditions and management objectives tailored to achieve these outcomes developed by MABI's consulting forester. Here, we have synthesized the desired future condition for each individual stand and condensed them into an overarching future forest condition that would be desirable for the entire forest system.

Northern hardwood forest system: desired future condition

The desired future forest condition for this system is a healthy, diverse, uneven-aged, high-quality northern hardwood stand that demonstrates the characteristics of a well-managed, working Vermont forest made up of predominately native species. A forest composed of a diversity of tree species and age classes, abundant diverse forms of woody debris, and one that is resilient to pests, pathogens, and changing environmental conditions and disturbances. This system will retain legacies from the past, provide exceptional recreational and interpretation opportunities, and will continue to provide habitat for a diversity of wildlife.

Plantation Forest System

The plantation forest system at MABI is characterized by the many managed tree plantations that exist in various stages of development across the property. Approximately 124-acres of MABI are plantation forests comprised of Norway spruce, white pine, red pine, scots pine, and European larch. Many of these plantations were established in the late 1800s on abandoned and often degraded pasture land. These historic plantations are the product of some of the earliest examples of scientific forest management in the United States. As these plantations forest systems have developed, they have been tended and thinned to as a means of continually improving growing conditions for the most vigorous trees. In the 2000s, management of these plantations continued to focus on intermediate and even-aged silvicultural treatments to improve the growing conditions of the highest quality trees. In addition, the management team also began to explore alternative tactics aimed at transitioning some of the plantations to more of a northern hardwood forest type.

The plantation forest system affords visitors a unique opportunity to experience the history of forest management at MABI and also provides practitioners examples of sustainable plantation management. In several of the plantations, mangers are beginning to transition these stands to a condition where large plantation trees remain as a legacy of past management, but natural hardwood regeneration is actively encouraged.

Plantation forest system: desired future condition

The desired future condition of the Plantation Forest System would be, in select locations, a healthy plantation that is dominated by species of artificial origin, is resistant to pest and pathogen stressors, and one which serves as scenic and functional living example of the legacy of plantation management. In other stands, remnants of old plantations remain in the form of large trees but the composition will have shifted towards a mixture of softwood and hardwood species, most of which regenerated naturally on the site. Diversity in age, composition, and structure has increased and these stands show resistance and resilience to forest disturbance.

Hemlock-Hardwood Forest System

The Hemlock-Hardwood forest system is characterized by stands which contain more than 30% of eastern hemlock in the overstory. This system encompasses approximately 135-acres and includes some of the oldest naturally regenerated stands at MABI. This system contains a mixture of both coniferous and deciduous trees. While eastern hemlock is the most common tree species present in this system, eastern white pine, sugar maple, northern red oak, American beech, and yellow birch are also present. While some areas would be considered a *hemlock-forest* natural community, areas where tree species area mixed would be classified as *hemlock-northern hardwood* natural community. These stands are diverse in species and in age structure ranging from even-aged to uneven-aged in some stands. There are exceptional recreational values present in these stands with viewsheds of the surrounding landscape and of a mature forest with large legacy trees.

Past management has been limited due to steep slopes in some areas but in the last ten years uneven-aged treatments and intermediate thinning have been prescribed. Future management has been proposed in this system to include continued use of intermediate thinning and, in select areas, single tree and small group selection as a means of diversifying the stand composition and structure.

Hemlock-hardwood forest system: desired future condition

The desired future condition of this forest system is an uneven-aged, diverse hemlock-northern hardwood forest. The forest will contain a diverse mix of species and age classes, abundant and diverse forms of downed woody debris and standing dead trees, and will express resiliency to pests, pathogens, and changing environmental conditions and disturbances. This system will retain legacies from the past and provide exceptional recreational, scenic, and interpretation opportunities, and continue to provide habitat for a diversity of wildlife.

Culturally and Ecologically Significant Areas

Cultural and ecological significant areas are found throughout the forests of MABI. Culturally and historically significant areas include the carriage road network and the associated trails which represent both recreational and interpretational assets. MABI is a living exhibit showcasing the progression of forest stewardship through the last century. Legacies of this past management are present in the form of old trees which grew up in once green pastures and views of the original plantations which provide critical visual links to the region's past. Current management seeks to maintain the condition of the carriage roads, legacy trees, and recreational trails. Scenic views from the roads and trails are also identified as a critical value to be maintained.

Ecologically significant areas have been identified across MABI and are incorporated into long-term forest management planning. Wildlife habitat both aquatic and terrestrial are currently being monitored and management is tailored to protect these ecological resources. Current management aims to buffer significant ecological areas and, in some cases, looks to enhance wildlife features through planned management.

Culturally and Ecologically Significant Areas: desired future condition

The desired future condition of the culturally and ecologically significant areas across MABI is one in which visual links to the long history of forest management and forest succession are highlighted throughout MABI. Carriage road and trails continue to provide exceptional recreational opportunities to visitors of MABI. Scenic viewsheds are maintained and enhanced throughout MABI and waterbodies, waterways, and significant wildlife habitat are adequately.

Conclusion

This report is designed to build upon previous planning efforts by presenting a framework for the integration of adaptive management techniques. An adaptive management approach calls for continuous and systematic re-evaluation of management goals and outcomes. The adaptive management framework developed here, should be re-evaluated when the current *Forest Management Plan and Environmental Assessment* is updated in the future.

Chapter 4: Assessing Forest Vulnerability

The forests of the Vermont and the Northeastern United States are a product of a long history of changing environmental and social conditions. A period of rapid and dramatic change occurred across the Northeast in the mid to late 1800s when a predominantly forested landscape was cleared for agricultural use. Much of the land cleared for agriculture was then abandoned in the early-mid 1900s as farmers moved west to more fertile lands. Following this period of farm abandonment, forests began a process of rapid regrowth which continued to until the late 20th century. In the last thirty years we have seen forest cover in the Northeast decline again as a results of increased residential development. Forests of the Northeast are products of these past disturbances and continue to be shaped by human and natural forces to this day.

Today, forests are a defining feature of the Northeast and provide a wide range of natural goods and services. However, forest systems across the region are faced with new challenges. The future condition of our forests are dramatically uncertain as new pests, pathogens, invasive species, shifting climatic regimes and disturbance patterns, changing patterns of property ownership, and land use changes all interact in unique and challenges ways. Identifying the vulnerabilities to these changes for each of the forest systems present in MABI is one of the most important steps in beginning the process of identifying management options that will conserve forest resource in the long-term. By first identifying the *potential impacts* on forest systems and characterizing the system's current resiliency or *adaptive capacity,* we can assess the overall *vulnerability* of that forest system.

This chapter outlines the process of conducting a vulnerability assessment. We begin by synthesizing the results from regional studies and assessments looking at the observed and projected climate related impacts on forests. We then evaluate the current adaptive capacity or inherent resiliency of the forest systems at MABI. The potential impacts and identified adaptive capacities are then used to develop a vulnerability assessment for each forest system.

Vulnerability assessments, in the context of natural resource management, are essential tools to help identify the resources that are at risk to the potential and projected impacts of environmental change (Swanston et al. 2016). Vulnerability assessments use relevant scientific information, quantitative analysis, and expert opinion to identify and determine the degree to which a given system is susceptible to the negative impacts of global environmental change. Vulnerability assessments can take many forms, but for the purposes of this report we will rely on the definition used by the *Forest Adaptation Resources* publication developed by Swanston et al. (2016). This publication breaks down vulnerability assessments into two main components. The first component is *potential impacts* and the second is *adaptive capacity*. Potential impacts are the direct and indirect consequences of global environmental change on forest systems. Adaptive capacity is the ability of a resource or natural system to accommodate or cope with potential impacts (Swanston et al. 2016).

Potential Impacts

Climate change poses a serious threat to sustaining forest forest function in the short and long-term. In the Northeast United States, annual temperature has increased by an average of 2.4 °F (1.3°C) between 1901 and 2011 (Janowiak et al. 2018). Temperatures across all seasons warmed during this period and warming was greatest during the winter months. Precipitation regimes have changes with an increase of annual rainfall and number of extreme precipitation events occurring over the last century. Annual snow fall has decreased across the region and the impacts of climate change have also been observed in the measured reduction in lake ice, lengthening of the growing season, and subsequent shifts in tree phenology (Janowiak et al. 2018)..

Based on temperature and precipitation projections derived from downscaled simulations of climate models, temperature is expected to continue to increase across all seasons over the next century under a range of climate scenarios (Janowiak et al. 2018). Precipitation is projected to increase in the winter and spring seasons across a range of climate scenarios. Projections for summer and fall precipitation is more variable but, intense storm events are expected to become more frequent in the next century. Winter snow fall is projected in continue to decrease as temperatures increase and more snow falls as rain (Janowiak et al. 2018).

Potential impacts on forest systems are projected to change in the next century. Cold adapted temperate and boreal species such as red spruce and balsam fir are projected to experience a reduction in suitable habitat in the next century (Janowiak et al. 2018). Species with wide habitat ranges such as red maple, northern red oak, black cherry, black birch, and American basswood may see increased suitable habitat in the next century. Changes in habitat suitability for many other common tree species will depend greatly on location, site conditions, disturbance, and management. Forest composition across New England is projected to change across the region but these compositional changes are not projected to occur for at least another century in the absence of major disturbance or alternative management approaches (Janowiak et al. 2018).

Additionally, changes in future forest productivity is projected to increase in the absence of major stressors across the region. Future productivity will depend greatly on levels of carbon dioxide fertilization, availability of water and nutrients, successional dynamics, disturbance, and species migration (Janowiak et al. 2018). Forest productivity is an important metric of the function of forests as it indicates the rate at which forest sequester carbon and accumulate biomass. Future productivity of the forest systems of MABI will be analyzed in later chapters.

A vulnerability assessment was conducted for Marsh-Billings-Rockefeller National Historical Park in 2014 with the assistance of the National Park Service's Climate Change Response Program (Fisichelli et al. 2014). The goal of this assessment was to gain insights into the potential impacts of climate change on forest systems present in MABI. The assessment focused primarily on model projections of changing suitable habitat for 80 tree species.

Model outputs from two climate scenarios, "least change" and "major change", show a decrease in habitat suitability for 10 tree species, minor changes for 24 species, and increases in habitat for 48 species at MABI (Fisichelli et al. 2014). Among the trees expected to see a decrease in suitable habitat as a result of these analyses are such northern species as balsam fir, paper birch, and quaking aspen (Additional materials III). Trees that are projected to see no change or show mixed results for both climate scenarios are American beech, yellow birch, eastern hemlock, red pine, and white pine. Trees that show an increase in projected habitat suitability in this study under both climate scenarios include the oaks, elms, and hickories to name a few. Under the "major change" scenario, several oak, hickory, and pine species uncommon or absent in MABI gain suitable habitat in central Vermont in the coming decades (Fisichelli et al. 2014).

Habitat suitability for the several planation species native to Europe is uncertain under climate change scenarios. The vulnerability analysis for MBR did note that Norway spruce, scots pine, and European larch might experience some reduction in suitable habitat (Fisichelli et al. 2014). These species appear to be especially vulnerable to drought. Managers have observed that Norway spruce is currently declining in some places on MABI grounds.

Potential impacts from invasive species, pests, and pathogens was addressed in the 2014 vulnerability assessment as well. It was noted that recent efforts to remove invasive species from MABI will reduce potential future impacts of these species. Invasive earth worms have been observed in several sites throughout MABI which might pose additional challenges for regeneration on some sites. Pest impacts have been observed to be moderate over the past 15 years, though the likely expansion of hemlock woolly adelgid and the emerald ash borer into MABI over the next two decades will pose a significant challenge to mangers looking to maintain eastern hemlock and white ash as overstory components in the forest. The inevitable loss of large proportions of eastern hemlock and white ash will push managers to develop plans to accommodate these shifts in ways that maintain the function of the forest systems.

In addition to identifying potential future impacts to forest resources in MABI, the assessment highlighted potential challenges for culturally significant resources. Large legacy trees along carriage roads and retained within transitioning plantations might be at a higher risk of wind throw on exposed sites due to their advanced age and height. Finally, the network of carriage roads and walking trails might be more vulnerable to flood and erosion damage if precipitation events continue to intensify in the future (Fisichelli et al. 2014).

Adaptive Capacity

Adaptive capacity, also referred to as ecological resilience, is the ability of a species or system to accommodate or cope with the potential impacts of global environmental change (Holling 1973, IPCC 2007, Janowiak et al. 2018). In this section we will highlight the factors which contribute to *high*, *moderate*, and *low* levels of adaptive capacity present in the forest systems of MABI. It is assumed that higher adaptive capacity is directly related to a reduction in vulnerability (Janowiak et al. 2018). We then use forest inventory data collected in 2012 and 2017 to assess the current condition and adaptive capacity for each forest system present in MABI.

There are specific factors which have been shown to support adaptive capacity or resiliency in species and ecosystems (Janowiak et al. 2018). Adaptive capacity is a concept that is related and can be used interchangeably with *ecological resilience*. The resilience of ecological systems was first described by C.S. Holling (1973) as “the measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationship between populations or state variables.” *Ecological resilience,* which is a term used more widely today, builds on the early understanding of resilience and is defined as the “amount of disturbance that a system can absorb without changing stability domains” or stable states (Gunderson, 2000). Essentially, a system is *resilient* if it can maintain or regain its fundamental function after a disturbance occurs. Biological diversity and the diversity of functional groups of species has been shown to play an important role in ecological resilience (Elmqvist et al., 2003). Another critical element to ecological resilience is the diversity of adaptive responses among functional groups of species to disturbance (Elmqvist et al., 2003). It is argued within the scientific community that the maintenance and promotion of ecological resilience and adaptive responses within forest systems should be a management objective of high priority when planning for future uncertainty (Duveneck, Scheller, & White, 2014; Gunderson, 2000; Joyce et al., 2009; Millar, Stephenson, & Stephens, 2007; Puettmann, 2011).

Ecological resilience and adaptive capacity can be promoted or enhanced by a number of means but, we have chosen to highlight two basic factors. First, *diversity* is directly related to resilience. By promoting a diversity of species present within the forest you are increasing the potential pathways for recovery following a disturbance. While species diversity is very important, we can also assess the diversity of age-classes in the forest and also the diversity of individual species related traits that exists within the system. Multi-aged forest systems are often more resilient and therefore less vulnerable to major disturbances. Individual tree species have unique functional traits which enable them to utilize resources, respond to changes, and reproduce. Promoting a diversity of these traits within the forest system can assist in building adaptive capacity.

The second basic factor of adaptive capacity is *connectivity* (Janowiak et al. 2018). Highly connected forests and landscapes are less vulnerable to changing conditions. Fragmented forest landscapes present challenges for tree species and wildlife to move as growing conditions or habitat requirements change. Given the projected changes in suitable habitat for many species in our region, promoting a more connected landscape can assist in the dispersal of organisms across the landscape. Additionally, tree species or forest communities that have restricted habitat requirements will be more vulnerable to change than tree species and communities that have wide habitat requirements.

In addition to adaptive capacity, forest systems have the potential to mitigate potential impacts. Through the storage and sequestration of carbon, forest systems play a major role in climate regulation.

We analyzed forest inventory data collected at MABI from 2012 and 2017 to assess the current condition and adaptive capacity of each forest system (Table 1). Species composition, diversity, adaptive capacity, and above ground biomass were determined and used for our evaluation. To assess adaptive capacity, we utilized relative *adaptability scores* for each individual tree species developed by the US Forest Service/Northeast Research Station's *Tree Atlas* initiative (Iverson et al. 2008). This approach has also been used in the recently published *Vulnerability Assessment and Synthesis for New England and New York* (Janowiak et al. 2018).

Adaptability scores are a metric used to describe an individual tree species' ability to adapt and respond to environmental change. Individual tree species traits (shade tolerance, drought tolerance, regeneration ability, etc.) and characteristics related to how trees respond to disturbance (tolerance to insects and disease, browse, fire, harvests, etc.) are both taken into account (Kabrick et al. 2017). Scores range from 0-8.5 and stands with weighted average scores less than 3.3 indicate lower adaptability (**L**), scores between 3.3 and 5.2 indicate moderate adaptability (**M**), and scores greater than 5.2 indicate higher adaptability potential (**H**) for that forest system (Kabrick et al, 2017).

To explore the full in-depth analysis of current forest conditions, see **Additional Resources: Section I** at the end of the report

Forest System Adaptive Capacity Summary Table							
Forest System	***Basal Area (ft^2/acre)***	***Trees Per Acre***	***Species Richness***	***Species Diversity***	***Species Evenness***	***Adaptability Score***	***Biomass (ton/acre)***
Northern Hardwood	105	146	16	1.37	0.69	3.12 (L-M)	69.00
Plantation	150	133	16	1.50	0.73	3.10 (L-M)	95.37
Hemlock-Hardwood	177	193	11	1.19	0.59	2.44 (L)	98.47

Table 1: Forest system adaptive capacity summary table takes average diversity and adaptability scores across understory, midstory, and overstory classes and other measures to compare forest systems**.** Adaptability scores are presented with L (low), M (moderate), and H (high) average adaptability scores.

Park Vulnerability

Vulnerability for each forest system present in MABI was analyzed based on current findings from the two reports cited in previous sections and the expert opinions of resource managers. Each forest system is presented with the associated potential impacts, adaptive capacity, and overall assessment of vulnerability. The vulnerability of each system is determined by the interaction between potential impacts and stressors and the adaptive capacity of the system. Vulnerabilities for each system is described in detail and is presented is classified as *low*, *medium*, or *high.*

Northern Hardwood Forest System Vulnerability Assessment

Potential impacts

As the temperature continues to warm and precipitation and storm events continue to intensify, shifting climate condition will interact with existing and new stressors such as insects and disease. The changes in climate will likely impact Northern Hardwood systems through changes in soil temperature and moisture. These changes could lead to drought like conditions which could impact the growth and regeneration success of certain tree species such as sugar maple (Janowiak et al. 2017). As wind events continue to intensify as models predicts, shifting disturbance patterns are expected. This could cause more frequent or widespread windthrow events leading to shifting light conditions and therefore altered regeneration responses in these systems. Changes in climatic conditions will also interact and in some cases may amplify stressors related to invasive plant species establishment, herbivory from white tail deer, and forest pests such as hemlock woolly adelgid (Janowiak et al. 2017).

The suitability of habitat for several species that are found in this forest system are projected to shift in the next century under a warming climate. Yellow birch and sugar maple may be at risk of a reduction in suitable habitat under the most extreme warming projections. Red maple appears to be well suited for changing environmental conditions. Common species such as American beech and white ash are projected to see increase in habitat suitability but they may not be able to capitalize on these favorable growing conditions due to persistent threats posed by pests and pathogens.

These potential impacts will ultimately interact leading to unique challenges moving forward. The degree to which these potential impacts will shift the conditions of this forest system greatly depends on the specific site and management. Sites that are prone to drought or are not as rich may be at higher risk.

Adaptive capacity

The Northern Hardwood Forest System of MABI are diverse in species and abilities to cope with disturbance (Figure 3, Table 2). These systems across New England are well adapted and are expected to expand their range Northward into areas that may have been too cold or moist in previous years while seeing a reduction in along their southern edge. This forest system in MABI has the highest average adaptability score between the three forest systems. While the understory appears to be more vulnerable to changing conditions, current management is working to increase the abundance of desirable species established in the understory. Sites within this system which are richer and are less prone to drought like conditions may be more adapted to future changes.

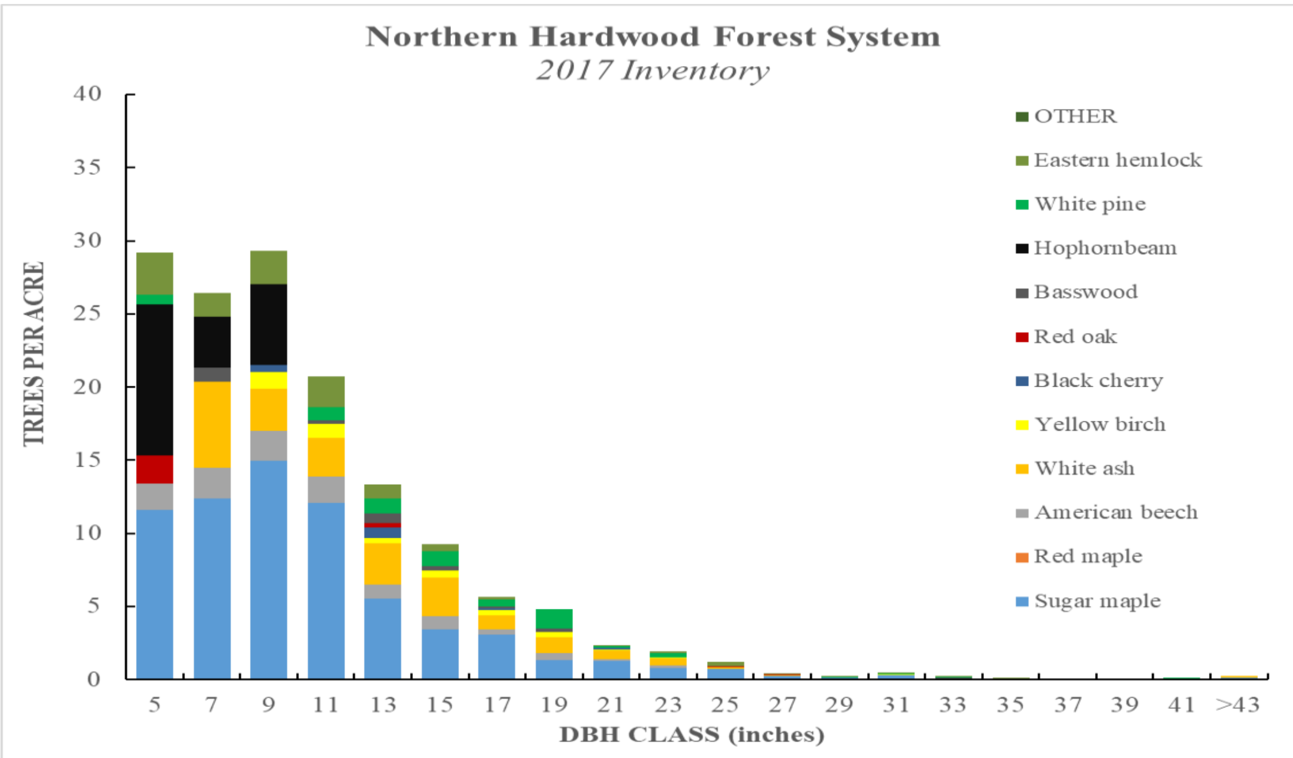


Figure 3: 2017 Northern Hardwood DBH distribution. Other species include black birch, and paper birch.

Northern hardwood forest system summary table							
2012	**Size Class**	**Basal Area (ft^2/acre)**	**Trees Per Acre**	**Species Richness**	**Species Diversity**	**Species Evenness**	**Adaptability Score**
	Overstory	**77**	**51**	14	1.91	0.72	4.28 (M)
	Midstory	**32**	**103**	11	1.84	0.77	4.38 (M)
	Saplings	NA	252	13	0.81	0.67	1.51 (L)
	Seedlings	NA	3948	25	1.11	0.71	2.41 (L)
	TOTAL/ AVERAGE	**109**	**154**	**16**	**1.42**	**0.72**	**3.15 (L)**
2017	Overstory	**73**	**50**	12	1.74	0.7	4.23 (M)
	Midstory	**28**	**88**	11	1.63	0.68	4.6 (M)
	Saplings	NA	248	13	0.82	0.64	1.36 (L)
	Seedlings	NA	4114	25	1.09	0.62	2.21 (L)
	TOTAL/ AVERAGE	**101**	**138**	**15**	**1.32**	**0.66**	**3.10 (L-M)**

Table 2: Northern Hardwood forest system summary table. Adaptability scores range from 0-8.5 and stands with weighted average scores less than 3.3 indicate lower adaptability (**L**), scores between 3.3 and 5.2 indicate moderate adaptability (**M**), and scores greater than 5.2 indicate higher adaptability potential (**H**) for that forest system (Kabrick et al, 2017).

Vulnerability assessment

There are significant challenges facing this forest system with changing temperature and precipitation along with the forest pests, pathogens, and invasive species. However, current management, natural succession, and high quality of site across the system have reduced overall vulnerability to these stressors. The control and continued monitoring of invasive species has greatly contributed to the reduced vulnerability of this system. The overstory trees present are diverse and moderately adapted overall to changing environmental conditions. Overall, this system has a **Low-Moderately vulnerability** (Table 3)**.**

VULNERABILITY ASSESSMENT TABLE		
Northern Hardwood Forest System		
Potential Impacts	**Adaptive Capacity**	**Vulnerability**
Increased temperature resulting in potential shifts in soil temperature and moisture regimes, increased growing season/shifting phenology, shifting habitat suitability for tree species	Diverse overstory in species composition and structure with low-moderate adaptive capacity. Understory layers are diverse and have potential for moderate adaptive capacity. Diversity of species allows for multiple pathways for recovery as growing conditions change	**LOW-MODERATE**
Increased intensity of rain events may lead to risk of runoff and erosion	Waterways and waterbodies are adequately buffered, downed woody debris which absorbs and slows surface water flow is abundant throughout forest.	
Increased potential for drought causing stress to trees of all sizes and posing challenges for regeneration of some species.	Forests have been managed to limit crowding and maintain desirable stocking reducing risk of drought related stress. Sapling and seedling layers are diverse and have low-moderate adaptability.	
Invasive insects will likely pose threat in near and distant future (emerald ash borer greatest threat given presence of ash through this forest system)	Across overstory, midstory, and understory species richness is high, diversity measures are moderate, and adaptability is low-moderate overall. Forest is currently resilient to expected stressors such as nuisance species.	
Invasive insects will likely pose threat in near and distant future (emerald ash borer greatest threat given presence of ash through this forest system)	Across overstory, midstory, and understory species richness is high, diversity measures are moderate, and adaptability is low-moderate overall	
-	Mitigation potential is moderate-high. Biomass has increased in the past five years. Downed woody material has increased with this forest system.	
Herbivory from white tailed deer pose potential threat to successfully regenerating desired species		

Table 3: Summary of potential impacts, adaptive capacity, and vulnerability for northern hardwood forest system in the Mount Tom Forest

Plantation Forest System Vulnerability Assessment

Potential impacts

The potential impacts for this forest system are similar to that of the Northern Hardwood Forest System. The majority of the plantations throughout MABI are on sites that would likely grow northern hardwood species. In fact, many of the plantations are being managed to assist in the transition to a northern hardwood forest over time. For the sites where a well-managed plantation is the desired future condition, the potential impacts of specific pests and pathogens might be greater than in a northern hardwood forest because plantations are generally dominated by one or two overstory species. Changes in soil temperature and moisture could lead to the risk of drought stress on certain cites. Herbivory by deer is a potential future challenge in this system. As overstory plantation species are harvested and more growing space is allocated to regenerating species, browse pressure could pose a challenge to managers.

Adaptive capacity

The Plantation Forest System has similar diversity and adaptability measures as the Northern Hardwood Forest System. While the overstory is dominated by plantation species, the midstory does contain a desirable mix of species, primarily sugar maple, which increases the adaptive capacity of this system (Figure 5). The sapling layer has a low density of desirable species and a low adaptability score relative to the overstory and understory as a result. American beech is the second largest component of the sapling layer, second to sugar maple, which poses a challenge to recruiting the desired diversity into the larger size classes. The adaptability of the seedling layer is higher than the sapling layer given the presence and abundance of species such sugar maple (Table 4). However, white ash is the second most abundant species in the seedling layer which is less desirable given the high vulnerability of this species to the Emerald Ash Borer (EAB) which is projected to cause widespread Ash mortality. The management of these systems has worked to diversify the species composition and age structure which has led to increased adaptive capacity.

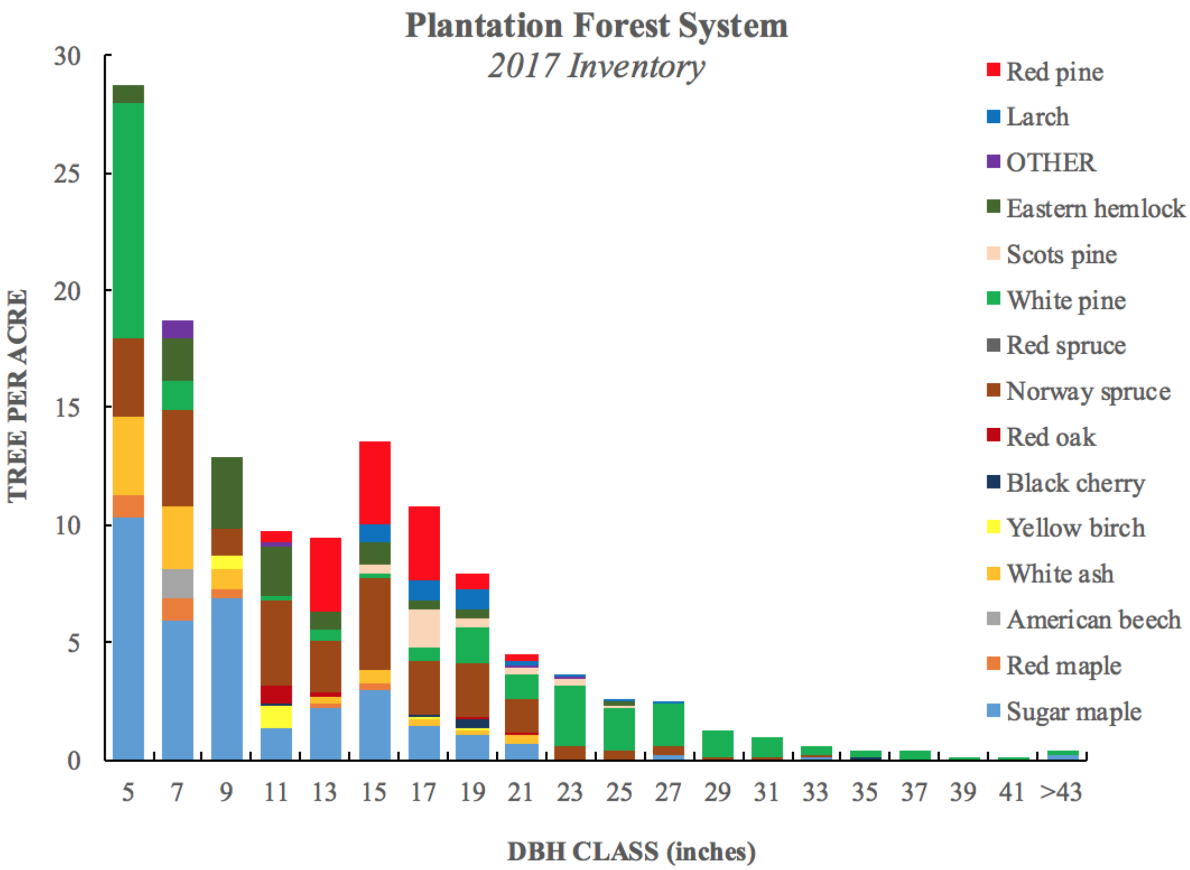


Figure 5: Plantation forest system 2017 DBH distribution. Other species include paper birch and big tooth aspen.

PLANTATION FOREST SYSTEM SUMMARY TABLE								
2012	***Size Class***	***Basal Area (ft^2/acre)***	***Trees Per Acre***	***Species Richness***	***Species Diversity***	***Species Evenness***	***Adaptability Score***
	Overstory	145	**77**	13	1.99	0.80	3.72 (M)
	Midstory	13	**54**	11	1.84	0.77	4.38 (M)
	Saplings	-	182	16	0.96	0.59	0.79 (L)
	Seedlings	-	5129	22	1.20	0.68	3.23 (L)
	TOTAL/ AVERAGE	**158**	**131**	**16**	**1.50**	**0.71**	**3.03(L-M)**
2017	Overstory	127	**69**	14	1.96	0.74	3.68 (M)
	Midstory	15	**66**	10	1.72	0.75	4.64 (M)
	Saplings	-	250	20	1.09	0.72	1.22 (L)
	Seedlings	-	5493	23	1.35	0.74	3.10 (L)
	TOTAL/ AVERAGE	**142**	**135**	**17**	**1.53**	**0.74**	**3.16(L-M)**

Table 4: Plantation forest system summary table 2012 & 2017. Adaptability scores range from 0-8.5 and stands with weighted average scores less than 3.3 indicate lower adaptability (**L**), scores between 3.3 and 5.2 indicate moderate adaptability (**M**), and scores greater than 5.2 indicate higher adaptability potential (**H**) for that forest system (Kabrick et al, 2017).

Vulnerability assessment

These systems face similar challenges as do the other forest systems. Forest pests and pathogens will pose a challenge for managing in these systems moving forward as will shifts in soil temperature and availability of water and nutrients. The control and continued monitoring of invasive species has greatly contributed to the reduced vulnerability of this system. The overstory trees present are diverse and moderately adapted overall to changing environmental conditions. Overall, this system has a **Low-Moderately vulnerability** (Table 5)**.**

VULNERABILITY ASSESSMENT TABLE		
Plantation Forest System		
Potential Impacts	**Adaptive Capacity**	**Vulnerability**
Increased temperature resulting in potential shifts in soil temperature and moisture regimes, increased growing season/shifting phenology, shifting habitat suitability for tree species	Diverse overstory and midstory in particular in species composition and structure with low-moderate adaptive capacity. Understory layers are diverse and have potential for moderate adaptive capacity. Diversity of species allows for multiple pathways for recovery as growing conditions change	**LOW-MODERATE**
Increased intensity of rain events may lead to risk of runoff and erosion	Waterways and waterbodies are adequately buffered, downed woody debris which absorbs and slows surface water flow is abundant throughout forest.	
Increased potential for drought causing stress to trees of all sizes and posing challenges for regeneration of some species.	Forests have been managed to limit crowding and maintain desirable stocking through thinning and regeneration harvests, reducing risk of drought related stress. Sapling and seedling layers are diverse and have low-moderate adaptability.	
Invasive insects will likely pose threat in near and distant future.	Across overstory, midstory, and understory species richness is high, diversity measures are moderate, and adaptability is low-moderate overall. Forest is currently resilient to expected stressors such as nuisance species.	
Projected reduction in suitable habitat for some tree species and uncertain suitability of European species	New plantations are being planted which are of mixed species and other plantations are being transitioned to mixed conifer-hardwood stands	
-	Mitigation potential is moderate-high. Downed woody material has increased with this forest system.	
Herbivory from white tailed deer pose potential threat to successfully regenerating desired species	-	

Table 5: Summary of potential impacts, adaptive capacity, and vulnerability for plantation forest system

Hemlock-Hardwood Forest System Vulnerability Assessment

Potential impacts

Given the dominance of eastern hemlock in these systems, hemlock woolly adelgid is likely to lead to decline in eastern hemlock overtime as winter temperatures continue to increase. Shifting temperature and moisture conditions will likely impact well drained and drought prone sites in the future.

Adaptive capacity

This forest system supports the largest amount of living and dead biomass lending itself to the highest mitigation potential across MABI. However, measures of diversity and adaptability are lowest in this system (Table 6). Currently the forest system is dominated by eastern hemlock which is at a high risk of declining due to the forest pest, hemlock woolly adelgid (Figure 6). The dominance of a vulnerable species in the overstory does lead to a reduction in that systems potential ability to respond to environmental change. There are, on average, 11 species present across this forest system and therefore multiple pathways for recovery from a major disturbance do exist. Much like in the other forest systems in MABI, there is a low abundance of desirable tree species in the understory which does lead to a reduction in overall adaptive capacity.

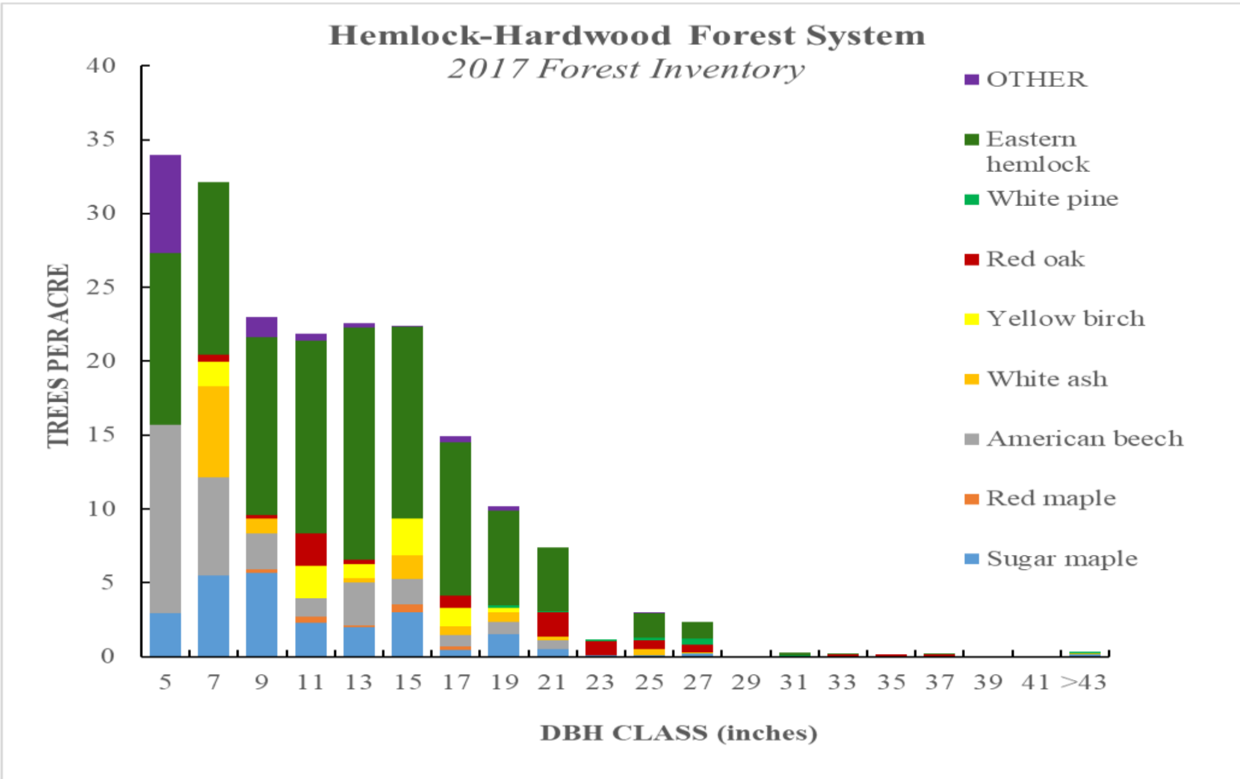


Figure 5: Hemlock-Hardwood forest system 2017 DBH distribution. Other species include paper birch, American elm, and hophornbeam.

HEMLOCK-HARDWOOD FOREST SYSTEM SUMMARY TABLE							
2012	*Size Class*	*Basal Area (ft^2/acre)*	*Trees Per Acre*	*Species Richness*	*Species Diversity*	*Species Evenness*	*Adaptability Score*
	Overstory	147	**89**	13	1.24	0.48	3.25 (L)
	Midstory	18	**78**	12	2.05	0.83	3.82 (M)
	Saplings	-	97	10	0.85	0.59	0.39 (L)
	Seedlings	-	6271	11	0.75	0.41	2.11 (L)
	TOTAL/ AVERAGE	**165**	**167**	**12**	**1.22**	**0.58**	**2.39(L)**
2017	Overstory	166	**119**	12	1.2	0.48	3.21 (L)
	Midstory	22	**100**	10	1.71	0.74	4.13 (M)
	Saplings	-	95	10	0.75	0.56	0.44 (L)
	Seedlings	-	2401	12	0.98	0.61	2.13 (L)
	TOTAL/ AVERAGE	**188**	**219**	**11**	**1.16**	**0.60**	**2.48(L)**

Table 6: Hemlock – Hardwood Forest system summary table 2012 & 2017. Adaptability scores range from 0-8.5 and stands with weighted average scores less than 3.3 indicate lower adaptability (**L**), scores between 3.3 and 5.2 indicate moderate adaptability (**M**), and scores greater than 5.2 indicate higher adaptability potential (**H**) for that forest system (Kabrick et al, 2017).

Vulnerability assessment

This forest system is characterized by the eastern hemlock which is at risk of major declines in the next half-century due to the hemlock woolly adelgid. While there are numerous species in the overstory, the lack of understory diversity and abundance does represent a vulnerability within the system. This system does provide the highest mitigation potential in MABI currently due to the high levels of biomass that is currently being stored in live and dead woody material. Given the expected decline in the dominance of eastern hemlock, this system has a **Moderate vulnerability** (Table 7).

VULNERABILITY ASSESSMENT TABLE		
Hemlock-Hardwood Forest System		
Potential Impacts	**Adaptive Capacity**	**Vulnerability**
Increased temperature resulting in potential shifts in soil temperature and moisture regimes, increased growing season/shifting phenology, shifting habitat suitability for tree species	Moderate diversity of overstory trees with low-moderate adaptability score. Lower adaptability of overstory due to abundance of Eastern hemlock. Sapling and seedlings are low in diversity and adaptability	**MODERATE**
Increased intensity of rain events may lead to risk of runoff and erosion	Continuous forest cover throughout forest system and waterways are well buffered	
Increased potential for drought causing stress to trees of all sizes and posing challenges for regeneration of some species.	-	

Invasive insects will likely pose threat in near and distant future (HWA poses greatest threat given presence of eastern hemlock through this forest system)	Temperatures have not warmed to the degree where HWA is a current issue in MABI. There is a diversity of tree species present within this forest system allowing for multiple pathways towards recovery if HWA does establish and begin causing mortality	
	This forest system is currently storing a considerable amount of biomass which does contribute to climate mitigation	

Table 7: Summary of potential impacts, adaptive capacity, and vulnerability for hemlock-hardwood forest system

Culturally and Ecologically Significant Areas: Vulnerability Assessment

Potential impacts

Projected increases in extreme weather events including rain and wind might put pressure on some of MABI's built infrastructure. Drainage systems on carriage roads, recreational trails, and logging roads may require additional monitoring and maintenance to ensure current systems are adequate to prevent erosion during heavy rain events. With an intensification of the climate system, extreme wind events and ice storms could pose threats to large old trees which line many of the road ways. Significant viewsheds may be altered due to disturbance events (insect and disease damage, etc.) and management and restoration efforts given projected changes. Ecologically significant areas experience additional stressors given projected changes to temperature, precipitation, and disturbance regimes. Waterways might be particularly vulnerable to warming conditions and increased prevalence of extreme precipitation events.

Adaptive capacity

The existing infrastructure of carriage roads has proven effective for the past several decades and is well maintained continued maintenance and monitoring will bolster this systems ability to deal with future stressors. The work that has been done to identify and monitor significant cultural and ecological features has increased the adaptive capacity of this system.

Vulnerability assessment

Culturally significant areas throughout MABI may experience some stress related to changing climatic and environmental conditions in the future. The level of monitoring of culturally and ecologically significant areas along with the continued maintenance of existing infrastructure reduce give this system a **Moderate** vulnerability (Table 8).

VULNERABILITY ASSESSMENT TABLE		
Culturally and Ecologically Significant Areas		
Potential Impacts	**Adaptive Capacity**	**Vulnerability**
Increased temperature	Forest cover mediates temperature. Forested paths and trails provide cool places for people to recreate	**MODERATE**
Increased intensity of rain events could put pressure on drainage systems throughout MABI	High degree of monitoring and maintenance conducted Park-wide	
Increased potential for extreme wind events and ice storms		
Increased prevalence of Invasive insects and pathogens	High degree of monitoring and assessment conducted Park-wide	
	High degree of community engagement	

Table 8: Summary of potential impacts, adaptive capacity, and vulnerability for northern hardwood forest system

Chapter 5: Evaluate

The evaluation of current management goals in the context of identified vulnerabilities is essential to achieving desired future outcomes in light of the stressors facing our forests. The evaluation of management goals is presented below in a series of tables outlining the challenges and opportunities for adaptive forest management given the identified vulnerabilities for each forest system.

Northern Hardwood Forest System: Management Evaluation

Adaptive Management Evaluation Table		
Northern Hardwood Forest System: LOW-MODERATE Vulnerability		
The DESIRED FUTURE CONDITION *for this forest system is a healthy, diverse, uneven-aged, high-quality northern hardwood stand that demonstrates the characteristics of a well-managed, native Vermont forest. A forest composed of a diversity of tree species and age classes, and one that is resilient to changing conditions. This system will retain legacies from the past in the form of large trees, provide exceptional recreational and interpretation opportunities, and will continue to provide high quality habitat for wildlife.*		
Long-Term Management Goal	**Management Challenges**	**Management Opportunities**
Maintain a diversity of desirable tree species	Maintaining a diversity of desirable species in sapling and mid-size (pole) classes may be challenging due to dominance of beech in some areas in the sapling class, browsing pressure, changing regeneration dynamics, and uncertain future soil temperature and moisture conditions	There exists a high diversity of tree species within the overstory and understory. Recruiting diversity from the seedling layers to the sapling midstory may be challenging but the opportunity exists given positive regeneration outcomes from recent harvests.

Establish a diverse uneven-aged forest (3 or more age classes established)	Two ages classes are established on most sites but getting a third age class of desired species recruited will be challenging in the years to come. Beech will continue to be a strong competitor with desired species such as sugar maple. White ash is the most abundant seedling species in this system but is considered less desirable given the presence of EAB.	Recent forest management has increased the representation of younger age classes of desirable species. With some control of beech in the sapling layer and focus on increasing representation of species moderately tolerant of shade opportunities exist to establish a diverse third age class.
Increase resistance to common and novel disturbances	Resistance to invasive species such EAB will most likely not be possible. White ash does well on the soils within MABI and is at high risk of decline and mortality as a result of EAB and other stressors.	Forest management has maintained desired stocking levels and has allocated adequate growing space to desirable species of accepting growing stock. Overstory trees are vigorous and will express resistance to stressors
Maintain and enhance resilience to common and novel disturbances	Resilience to common and novel disturbances is strongest in the overstory given the diversity and adaptive capacity of dominant tree species. The sapling layer and seedling layer are vulnerable to disturbance	Opportunities exist to work with the existing resilience expressed in the overstory and work with components of the understory to increase resilience by continued to focus on promoting diversity in composition and structure and recruiting desired species into the sapling and midstory classes.

Promote forest transition to increase adaptive capacity in the face of projected environmental change	High levels of uncertainty surrounds transition measures. Transition tactics may require approaches, such as larger harvest openings and some enrichment planting, that are unfamiliar to general public leading to challenging interpretation and justification	Overstory and understory are well adapted to shifting disturbances therefore there exists the potential for transition measures. Red oak and yellow birch are present in overstory and could be promoted on appropriate sites. Larger openings as have been planned for current management cycle will present opportunities to regenerate species that tolerate moderate light levels (increasing adaptive response diversity) and will provide opportunities for enrichment planting of future adapted species if desired
Retain large trees as biological and cultural legacies	Existing large trees are old and will be declining and therefore additional trees will need to be selected as successor	Large trees have been retained throughout this forest system and there are opportunities to increase the number of large trees retained within stands
Provide high quality wildlife habitat	Uncertain future conditions pose challenges for sustaining wildlife habitat.	Wildlife habitat features such as standing dead trees and downed wood material are present across the forest system and have increased in the last five years providing ample opportunity for current and future habitat enhancement in the near and long term if current levels are maintained and or increased.

Table 9: Forest Management Evaluation table for northern hardwood forest system in the Mount Tom Forest

Plantation Forest System: Management Evaluation

Adaptive Management Evaluation Table		
Plantation Forest System: LOW-MODERATE Vulnerability		
The DESIRED FUTURE CONDITION *The desired future condition of the Plantation Forest System would be, in select locations, a healthy plantation that is dominated by species of artificial origin, is resistant to pest and pathogen stressors, and one which serves as scenic and functional living example of the legacy of plantation management. In other stands, remnants of old plantations remain in the form of large trees but the composition will have shifted towards a mixture of softwood and hardwood species, most of which regenerated naturally on the site. Diversity in age, composition, and structure has increased and these stands show resistance and resilience to forest disturbance.*		
Long-Term Management Goal	**Management Challenges**	**Management Opportunities**
Maintain healthy plantations that are resistant to existing and novel stressors	With uncertainty around future forest conditions lower diversity systems might be at higher risk of disturbance related decline	New plantations can be managed with well-timed thinning to maintain vigor and reduce stressors related to changing soil temperature and moisture conditions
In designated areas transition plantations and establish a diverse uneven-aged forest (3 or more age classes established) of hardwoods and softwoods	Regeneration of third cohort is challenging given competition from beech, browsing pressure, invasive species, and other stressors	Many stands consist of two age classes and efforts have been on-going to regenerate a new cohort with the hopes of recruiting this new age class into the sapling class in the next ten years. Overstory, midstory, and regeneration layers are diverse and have moderate adaptive capacity. Opportunities exist to recruit desired species into the sapling layer.

Maintain and enhance resilience to common and novel disturbances	Plantations maintained as such are less resilient to common and novel disturbances	Opportunities exist to promote mixed species plantations and establish a second cohort within plantations to increase resiliency. Within areas transitioning to mixed northern hardwood stands with remnant plantation species interspersed, there already exists resiliency to disturbance and there is opportunity to increase these components
Promote forest transition to increase adaptive capacity in the face of projected environmental change	Some plantation species are projected to do poorly with changing climatic conditions	Opportunities exist as new plantation are established to select seed stock which is well suited to projected future conditions. In areas where northern hardwood components are being promoted, promoting future adapted species and even planting some species are options.
Retain large trees as biological and cultural legacies	Large plantation trees may be vulnerable to wind throw on exposed sites	Large trees exist across the forest system that are excellent candidates for legacy trees
Provide high quality wildlife habitat	-	Standing dead trees and downed woody debris have been recruited over the past five years providing opportunity for increased potential for habitat creation.

Table 10: Forest Management Evaluation table for plantation forest system in the Mount Tom Forest

Hemlock-Hardwood Forest System: Management Evaluation

Adaptive Management Evaluation Table		
Hemlock-Hardwood Forest System: MODERATE Vulnerability		
The DESIRED FUTURE CONDITION *for this forest system is an uneven-aged, diverse hemlock-northern hardwood forest. The forest will contain a diverse mix of species and age classes, abundant and diverse forms of downed woody debris and standing dead trees, and will express resiliency to pests, pathogens, and changing environmental conditions and disturbances. This system will retain legacies from the past and provide exceptional recreational, scenic, and interpretation opportunities, and will continue to provide habitat for a diversity of wildlife.*		
Long-Term Management Goal	**Management Challenges**	**Management Opportunities**
Maintain a diversity of desirable tree species	Maintaining a diversity across size classes is currently a challenge. Seedling and sapling layers show a strong representation of beech posing challenges for maintaining diversity through successional time.	While the overstory is dominated by eastern hemlock, northern red oak, sugar maple, and yellow birch are present and established. This allows for some management options in the overstory. Regeneration harvest would be needed to promote a greater representation of desirable species in the seedling and eventually the sapling layers.
Establish a diverse uneven-aged forest (3 or more age classes established)	While three age classes are present in some areas, younger age classes are represented primarily by undesirable species and hemlock which is at increasing risk of decline due to HWA.	Three age classes exist in some areas and targeted management could promote the establishment of a third age class in areas where only two exist currently. Additionally regeneration harvests could promote the establishment or more desirable species

Establish a diverse uneven-aged forest	Regeneration harvests may difficult to carry out given steep slopes or wet soils in some areas	Single tree selection or small groups could be created by felling and leaving woody material onsite for structural enhancement purposes
Increase resistance to common and novel disturbances	Eastern hemlock is extremely vulnerable to decline and mortality from HWA if established on site.	Thinning could improve vigor of some hemlock trees and other more desirable species present on site leading to increased resistance to stressors.
Maintain and enhance resilience to common and novel disturbances	Eastern hemlock is dominant currently in many areas and the expected decline and eventual loss of hemlock presents a challenge for sustaining resilience. Additionally, seedling and sapling layers are not diverse and have low representation of desired species	Diversity exists in the overstory and midstory which could be capitalized on by increasing representation of desired species relative. Hemlock regeneration could also be released to mitigate the expected loss of overstory hemlock
Promote forest transition to increase adaptive capacity in the face of projected environmental change	Challenges to promoting a transition to a future forest condition well adapted to projected changes exist mainly in the regeneration layer where diversity and adaptability is lowest within this forest system	Representation of red oak, white pine, and red maple could be increased and red spruce or another successor conifer could be planted to in advance of expected hemlock decline as a result of HWA.
Retain large trees as biological and cultural legacies	-	These stands are well suited for retention of large legacy trees
Provide high quality wildlife habitat	Challenges may arise in maintaining habitat quality for species utilizing the mature hemlock stands along the steep terrain in MABI given the threat of HWA	These stands currently provide high quality late successional habitat and could be managed to reduce the vulnerability to habitat loss related to HWA. See next section for management tactics.

Table 11: Forest Management Evaluation table for hemlock-hardwood forest system in the Mount Tom Forest

Culturally and Ecologically Significant Areas: Management Evaluation

Adaptive Management Evaluation Table		
Culturally and Ecologically Significant Areas: MODERATE Vulnerability		
The DESIRED FUTURE CONDITION*: Visual links to the long history of forest management and forest succession are highlighted throughout MABI. Carriage road and trails continue to provide exceptional recreational opportunities to visitors of MABI. Scenic viewsheds are maintained and enhanced throughout MABI and waterbodies, waterways, and significant wildlife habitat are adequately protected*		
Long-Term Management Goals	**Management Challenges**	**Management Opportunities**
Maintain and recruit large legacy trees along carriage roads and trails	Many large trees along road ways are advanced in age and may begin to show signs of decline.	The diversity of trees present in MABI provides options for new recruit selection
Maintain carriage road and trails	Projected increases in high volume precipitation events may put additional demand on drainage systems. Projected shorter and warmer winter conditions may create challenges for road maintenance and recreational access	Carriage roads have withstood many years of high use and extreme weather. Potential challenges are not immediate so there is an opportunity to evaluate the road networks and associated drainage systems.
Maintain, enhance, and create scenic viewsheds	Given proposed adaptive management tactics, some viewshed may be altered. Many classic plantations are either being re-established or transitioned to a mixture of conifers and hardwoods creating shifting viewsheds.	Proposed management will allow for the creation or enhancement of viewsheds throughout MABI

Maintain forest cover along waterways and waterbodies	Eastern hemlock is dominant along some of the small waterways and waterbodies and is projected to experience decline and even mortality due to HWA presenting challenges to maintaining continues canopy cover along some waterways	HWA is not present on the property currently therefore measures to increases the representation of other species along waterways are possible

Table 12: Forest Management Evaluation table for culturally and ecologically significant areas in the Mount Tom Forest

Chapter 6: Identify Adaptation Strategies

Due to the vulnerabilities identified in previous chapters, several challenges and opportunities exist as mangers seek to achieve the desired future conditions for the forest systems of MABI. While forest management has historically employed an iterative process of evaluating results from previous management decisions, new challenges related to global change may require managers to re-examine how they evaluate these management outcomes and also explore new or adaptations of traditional approaches to deal with novel challenges. As the impacts of invasive insects, climate change, and other interacting stressors related to global environmental change become more tangible, managers require reliable information on how best to promote healthy and resilient forests.

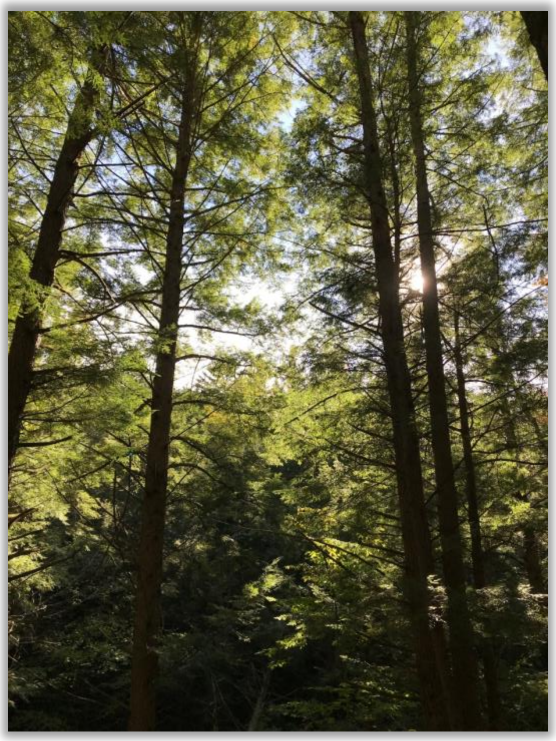
This chapter will present the current approaches to managing forests in the context of a changing disturbances, climatic conditions, and other novel stressors. The report will then identify and evaluate potential adaptive management actions that can be applied to address current and future vulnerabilities present within each forest system of MABI. This section will rely heavily on published research and the publication developed by the U.S. Forest Service called *Forest Adaptation Resources: climate change tools and approaches for land managers, 2nd edition* (Swanston et al. 2016).

Adaptive Silviculture

The practice of forest management in the United States has undergone changes in the last century and many examples of this progression are displayed at Marsh-Billings-Rockefeller

National Historical Park (MABI). The management at MABI has continued to progress and move towards incorporating multiple ecological, social, and economic objectives into long-term planning. This approach to management is often referred to as *ecological forestry*. Ecological forestry arose from a demand for integrated forest management which promoted ecological function and economic production while meeting other diverse goals and objectives. One of the primary objectives of ecological forestry is to understand and work with natural patterns and processes to achieve management objectives (Seymour and Hunter, 1999). Ecological forestry seeks to use silvicultural systems to manipulate forest stands in ways that emulate the natural disturbance patterns of the region prior to extensive human alteration (Seymour and Hunter, 1999). Ecological forestry principles look to restore elements of natural forests by emulating the frequency, severity, and spatial pattern of disturbances with the goal of enabling these systems to respond favorably to human disturbances such as harvesting (Seymour and Hunter, 1999).

The recognition of disturbance as a primary driver of ecosystem structure and function has led to the restructuring of silvicultural applications as natural disturbance emulating practices (O'Hara, 2013). Whereby, these reframed applications seek to direct stands in ways that restore ecosystem functions and biological diversity (Seymour, 1999, O'Hara, 2013). By emulating observed ecological processes, ecological forestry works to restore ecosystem function, conserve biodiversity, and achieve other social and economic objectives. Ecological forestry principles also promote a diversity of age structures and therefore allow for a greater diversity of tree species and habitat types to be present within the stand. Much of the forest in the Northeast is recovering from extensive land-use (i.e. agricultural clearing and widespread cutting) and is therefore somewhat uniform in age structure. Ecological forestry practices seek promote biodiversity conservation and forest resiliency by increasing the diversity of both species and structures within a given stand.



While ecological forestry is applicable in a wide range of forestry settings and has the ability to restore ecosystem function and foster increased resilience, a limiting factor in this approach is the dependence on the predictability of historical disturbance patterns. Today, natural disturbance regimes are being altered and are interacting with new disturbances with no historic analogue (Puettmann, 2010). Many of the tenets and approaches to ecological forestry remain relevant to achieving forest resiliency, but may require reframing and modification to fully address the increased variability and uncertainty of future environmental change.

Increasingly, forest managers are tasked with managing for the uncertainty around the variability of future environmental change. Global change is an umbrella term used to describe the composition of interacting historic and emerging agents of environmental change (Puettmann, 2010). Historically, forest managers have relied on concepts of ecological sustainability, historical variability, and ecological integrity to determine management decisions (Millar, 2007). As new invasive pest and pathogens, shifting climatic conditions, and other novel environmental stressors interact with our forest systems, managing based solely on past forest conditions might limit long-term biodiversity conservation and ecological resiliency (Millar, 2007).

Adaptive silviculture has emerged to address these novel challenges. Building on the principles of ecological forestry, adaptive silviculture aims to sustain ecological function and economic productivity in the face of uncertain challenges. These approaches aim to use silvicultural treatments to promote resistance and resilience to change and, in some cases, aid in the transition of the system towards a state that may be better suited for projected future conditions (Millar, 2007). In order to maintain ecological integrity and economic productivity over time, adaptive silviculture looks to enhance the forest's adaptive capacity by focusing on managing the functional components of the system.

Adaptive silvicultural approaches place biodiversity conservation and management of other ecosystem services in the context of global change. With the onset of potentially dramatic changes, a focus on maintaining and enhancing the functional components of the forest system will hopefully result in increased forest resilience. Forest resiliency can be enhanced by diversifying the compositional, structural, and spatial arrangement of trees within and among forest stands while encouraging regeneration of species well adapted to projected future conditions and disturbances.

Adaptive Silviculture Approaches (Resistance, Resiliency, And Transition)

In this period of uncertainty around future environmental conditions, forest managers are utilizing a toolbox approach, whereby traditional and novel treatments and practices are used together in new combinations to address current and future challenges (Millar et al., 2007). Silviculture has traditionally employed an iterative and adaptive process when evaluating the results of prescriptions and such an approach is increasingly important as managers strive to achieve diverse management objectives under changing and uncertain future conditions

(Puettmann, 2009; (M. K. Janowiak et al., 2014; Puettmann, 2011). Millar et al. (2007) developed a framework of management which included adaption and mitigation strategies that can be applied at the landscape and stand level. Options for adaptation under this framework include measures which increase a forest system's ability to *resist* change, options which promotes the *resilience* of the system, and options which anticipates the expected change and assist in the *transition* the forest systems towards a state that is more adapted to the future conditions (Millar et al., 2007) (Figure 6).

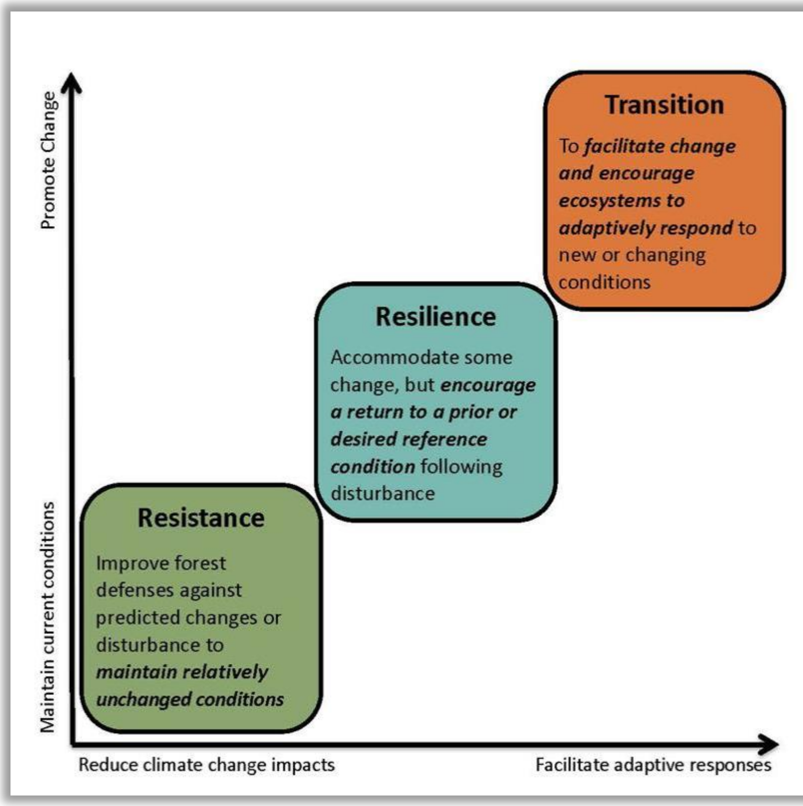


Figure 6: Adaptive silvicultural options (Nagel 2018)

Resistance measures are designed to protect the forest system from anticipated disturbances. These approaches are used where the forest system is of high economic, social, cultural, or ecological value and there is a desire or requirement that these systems be preserved as long as possible (Swanston et al. 2016). Tactics such as thinning to improve the growing conditions of desired species is an example of a resistance measure. These measures are often most effective in systems that have low vulnerability and are in a sense buffered from future changes. These approaches are best suited to meet short term objectives.

Management decisions which increase *resilience* anticipate potential impacts and promote the recovery of system function following a disturbance. Resilience measures enhance the system's ability to return to a desired state and maintain their function following a disturbance. Tactics which use small scale disturbances as a means of increasing the diversity of species and age classes are examples of these measures. These approaches are best suited for systems where there is moderate or high adaptive capacity present. The effectiveness of these approaches diminishes, much like resistance measures, as the degree of change increases.

Transition approaches are designed to accommodate future change by assisting an adaptive response within the stand (Millar et al. 2007). While resistance and resilience actions focus on maintaining the current composition or function of the system, transitional actions anticipate these changes and look to enhance existing components of the system that are expected to do best under future environmental conditions. Transition tactics often aim to shift the composition of species to reflect changes in suitable habitat through favoring certain species or actually planting species that are not present but are expected thrive under future conditions. These measures are often designed to meet long-term goals and are typically phased into management planning over time (Swanston et al. 2016, Millar et al. 2007).

In addition to management actions that promote adaptation to projected environmental changes there are very important *mitigation* measures that can be employed. These measures aim to reduce greenhouse gas emissions by sequestering carbon on site in live and dead biomass whereby reducing emissions and providing additional ecological benefits (Millar et al. 2007). By storing more carbon in both live and dead trees these actions can reduce long term impacts of climate change.

Adaptive Tactics

Managers at MABI have been working with the Northern Institute of Applied Climate Science (NIACS) to synthesize current vulnerabilities and identify adaptive management tactics that could be applied across MABI. NIACS has been working with other landowners across the region to incorporate climate change consideration into long-term planning and short-term actions. In addition to the work that the mangers at MABI have done with NIACS, MABI's forester Ben Machin and Kyle Jones (Ecologist) have convened annual gatherings of forestry professionals from across the State to walk the property and discuss management decisions for MABI. The results from these planning efforts have been used along with the *Menu of Adaptation Strategies and Approaches* developed by Swanston et al. (2007) to outline adaptive management tactics that can be applied in each forest system across MABI (Table 13).

Strategy 1: Sustain fundamental ecological function	**Strategy 6: Increase ecosystem redundancy across the landscape.**
1.1. Reduce impacts to soils and nutrient cycling.	6.1. Manage habitats over a range of sites and conditions
1.2. Maintain or restore hydrology	6.2. Expand the boundaries of reserves to increase diversity
1.3. Maintain or restore riparian areas	**Strategy 7: Promote landscape connectivity.**
1.4. Reduce competition for moisture, nutrients, and light	7.1. Reduce landscape fragmentation
Strategy 2: Reduce the impacts of biological stressors.	7.2. Maintain and create habitat corridors through reforestation and restoration
2.1. Maintain or improve the ability of forests to resist pests and pathogens	**Strategy 8: Maintain and enhance genetic diversity**
2.2. Prevent the introduction and establishment of invasive plant species and remove existing invasive species	8.1. Use seeds, germplasm, and other genetic material from across a greater geographic range
2.3. Manage herbivory to promote regeneration of desired species	8.2. Favor existing genotypes that are better adapted to future conditions
Strategy 3: Reduce the risk of long-term impacts of severe disturbances	**Strategy 9: Facilitate community adjustments through species transitions.**
3.1. Alter forest structure or composition to reduce risk of severity of wildfire	9.1. Favor or restore native species that are expected to adapted to future conditions
3.2. Establish fuel breaks to slow the spread of catastrophic fire	9.2. Establish or encourage new mixes o native species
3.3. Alter forest structure to reduce severity or extent of wind and ice damage	9.3. Guide changes in species composition at early stage of stand development
3.4. Promptly revegetate sites after disturbance	9.4. Protect future-adapted seedling and saplings
Strategy 4: Maintain or create refugia.	9.5. Disfavor species that distinctly maladapted
4.1. Prioritize and maintain unique sites.	9.6. Manage fore species and genotypes with wide moisture and temperature tolerances
4.2. Prioritize and maintain sensitive or at-risk species or communities	9.7. Introduce species that expected to be adapted to future conditions
4.3. Establish artificial reserves for at-risk and displaced species	9.8. Move at-risk species to location that expected to provide habitat
Strategy 5: Maintain and enhance species and structural diversity.	**Strategy 10: Realign ecosystem after disturbance**
5.1. Promote diverse age classes	10.1. Promptly revegetate sites after disturbance
5.2. Maintain and restore diversity or native species	10.2. Allow for areas of natural regeneration to test future-adapted species
5.3. Retain biological legacies	10.3. Realign significantly disrupted ecosystems to meet expected future conditions
5.4. Establish reserves to maintain ecosystem diversity	

Table 13: Menu of adaptation strategies and approaches (Swanston et al. 2016). Resistance strategies, resilience strategies, and transition strategies

Northern Hardwood Forest System: Adaptation Tactics

Adaptation Tactics			
Northern Hardwood Forest System			
ADAPTATION STRATEGY	**ADAPTATION APPROACH**	**ADAPTATION TACTICS**	**BENEFITS OR DRAWBACKS/BARRIERS**
Strategy 1: Sustain fundamental ecological function	1.4. Reduce competition for moisture, nutrients, and light	Thin within forest matrix (in between harvest gaps) to promote the growth of acceptable growing stock (AGS).	(+) Opportunity to select for crown forms resilient to ice loading (u-shaped crotches) (-) Potential for root and bole damage (-) Release of unwanted vegetation in understory where present
Strategy 2: Reduce the impacts of biological stressors	2.1 — Maintain or improve the ability of forests to resist pests and pathogens	Increase early detection and monitoring efforts and partner with other organization/volunteers where possible. EAB and HWA are priority for early detection.	(+) Leverage existing efforts by Forest Service and Vermont Agency of Natural Resources. Local volunteers could be trained as early detection agents
	2.1 — Maintain or improve the ability of forests to resist pests and pathogens	In preparation for EAB arrival, if ash is to be harvested use the opportunity to do so during a regeneration harvest. If it is desired to regenerate ash, low light condition will be adequate initially but ash does require intermediate light to reach the sapling size class. If some ash is retained in stands, select female trees.	
	2.2 – Prevent the introduction and establishment of invasive plant species and remove existing invasive species	Continue monitoring and yearly removal of invasive species	
Strategy 4: Maintain or create refugia.	4.1. Prioritize and maintain unique sites.	Identify areas within the forest system that have indicators of enrichment.	

		Rich sites can support a wider diversity of species.	
Strategy 5: Maintain and enhance species and structural diversity	5.2 — Maintain and restore diversity of native tree species	Use single tree and small group selection harvests (Single tree on enriched sites to recruit shade tolerant species such as sugar maple. Group selection is used to regenerate mid-tolerant species).	(-)Single tree selection might not successfully regenerate sugar maple on lower quality sites or where beech is well established in the understory
		Create larger gaps (>1/4th-acre) during harvest to promote natural regeneration of a wider variety of tree species.	(+) Increase diversity especially mid-tolerant species (+) Increase stand scale structural diversity (-) Aesthetics of larger gaps can be a concern
	5.3 — Retain biological legacies	Retain trees within larger gaps and permanently within the matrix. Make use of small reserve patches within managed stands.	(+) Increase structural diversity, wildlife habitat, and future seed source. (+) Maintains carbon storage potential within stands
	5.4. Establish reserves to maintain ecosystem diversity	Retain reserves within forest system to provide deep shade, dead wood recruitment, wildlife habitat, and alternative pathways for recovery following disturbance. Managers could explore different reserve area sizes. Small 1/10th acre reserve patches could be retained where single tree and group selection is prescribed or reserves could be aggregated in select locations.	(-) May be difficult to establish reserves in small stands. (+) Reserves allow for the retention of large trees, promotion of late successional forest conditions and habitat, and provide options for future management.
Strategy 7: Promote landscape connectivity.	7.1. Reduce landscape fragmentation	Continue to work with neighbors to coordinate harvest when necessary. Continue interpretive and education programing to promote and demonstrate forest stewardship	

		practices that can be applied across the region.	
Strategy 8: Maintain and enhance genetic diversity	8.1. Use seeds, germplasm, and other genetic material from across a greater geographic range	Consider enrichment planting with species adapted to projected future forest conditions. Site specific planting within harvest gaps may promote future diversity and resiliency to changing environmental conditions.	(+) Increases potential for forest adaptive capacity by promoting a transition towards communities represented by tree species projected to have suitable habitat in the future. (-) Additional costs to purchase, plant, and protect seedlings.
	8.2. Favor existing genotypes that are better adapted to future conditions	Identify existing tree species which are projected to gain or maintain suitable habitat in the future to encourage with regeneration harvest. (Northern red oak, red maple, yellow birch).	
Strategy 9: Facilitate community adjustments through species transitions.	9.1— Anticipate and respond to species decline	Continue to harvest ash as that is at it economic and or biological rotation age. Removal of ash should be a part of a silvicultural regeneration method. Regeneration of ash can be promoted to establish a future cohort which could persist following expected impacts to overstory.	(-) Single tree selection (small gap creation) may regenerate ash on rich sites but ash seedlings will require additional light to grow into the sapling size class. (+) Larger gap creation during harvest can regenerate a wider range of species.
	9.6 — Protect future-adapted regeneration from herbivory	Create larger gaps and include more opening to "overwhelm" browsing deer. Leave slash within gaps to deter browsing. Use physical protection on highly desirable species in the regeneration layer with light weight deer fencing	(-) Additional or larger gaps which might be not aesthetically pleasing. Protecting individual seedling might be cost prohibitive
	9.7 — Establish or encourage new mixes of native species	Plant future-adapted tree species (e.g., oaks, hickories, black birch)	(-) Larger gaps are needed, which may be hard to create (-) Planting is an unusual practice in these stands (-) Additional cost

Strategy 10: Realign ecosystem after disturbance	10.1 — Prepare for more frequent and more severe disturbances	Disturbances (e.g., wind, ice storms) to create opportunities for increasing tree species and structural diversity.	(-) Hard to plan for – can't control when/where disturbance occurs
	10.2. Allow for areas of natural regeneration to test future-adapted species	Use group/patch selection harvests to regenerate a wider range of tree species. Consider enrichment planting within largest of harvest openings.	

Table 14: Adaptation tactics table for northern hardwood forest system

Plantation Forest System: Adaptation Tactics

Adaptation Tactics			
Plantation Forest System			
ADAPTATION STRATEGY	**ADAPTATION APPROACH**	**ADAPTATION TACTICS**	**BENEFITS OR DRAWBACKS/BARRIERS**
Plantations maintained			
Strategy 1: Sustain fundamental ecological function	1.1 — Maintain or restore soil quality and nutrient cycling	Winter harvest may be preferable in Norway spruce to limit root damage.	
	1.4. Reduce competition for moisture, nutrients, and light	Schedule periodic thinning in new plantations in accordance with acceptable silvicultural guide.	
Strategy 2: Reduce the impacts of biological stressors.	2.3 — Manage herbivory to protect or promote regeneration	Newly planted seedlings might require additional protection from herbivory	(-) Additional cost to protect new seedlings
	2.2 – Prevent the introduction and establishment of invasive plant species and remove existing invasive species	Continue annual monitoring and removal efforts	(+) Currently underway
	3.3 – Alter forest structure to reduce	Select trees for retention based vigor, wind	

Strategy 3: Reduce the risk of long-term impacts of severe disturbances	severity or extent of wind and ice damage	firmness, and desirable live crown ratios (preferable >30%). Retain trees post regeneration harvest in groups where possible to reduce potential impact of wind.	
Strategy 5: Maintain and enhance species and structural diversity.	5.1 – Promote diverse age classes	Overstory removal and subsequent replanting could be staggered 5-10yrs. This would create multiple age classes of newly planted trees	
	5.2 – Maintain and restore diversity of native species	New plantations can be native species. Plantations could be mixed with multiple conifers and hardwoods interplanted. If natural regeneration occurs, desirable species that are free to grow could be retained within plantations.	
	5.3 — Retain biological legacies	Retain single trees within group openings when appropriate (as to not alter desired post-harvest light conditions). Continue to retain trees within stands beyond economic rotation age to enhance structural complexity. Reserve patches could be identified and maintained within stands.	
	8.2 — Favor existing genotypes that are better adapted to future conditions	Where plantation species are replanted, use local stock (heritage) when available.	(+) Plantation species have large native ranges and diverse genotypes (-) Some native seed sources are hard to obtain and could be poorly suited for future environmental conditions.

Strategy 8: Maintain and enhance genetic diversity	8.2 — Favor existing genotypes that are better adapted to future conditions	White pine and red spruce are found on the property currently and could be considered for plantation stock. Additionally, mixed plantations of softwoods and hardwoods could be considered. Oaks (white and red), hickories (bitternut and shagbark), white pine, and red spruce could be considered for local planting stock options.	
	8.3 — Increase diversity of nursery stock to provide those species or genotypes likely to succeed	Research potential seed sources adapted to projected climate conditions. Managers could look into pine species found currently in more southern regions which are projected to gain suitable habitat in this region in the next century.	
Strategy 9: Facilitate community adjustments through species transitions.	9.1— Anticipate and respond to species decline	Thin stands to improve vigor and reduce risks from drought	(+) Many stands can have one additional thinning before end of rotation (+) Above also provides opportunity to try new ideas and further assess climate change impacts
	9.1— Anticipate and respond to species decline	Establish desired plantation species in the near-term (next 2 decades). Plant a mixture of species to "hedge" against potential future decline or disturbance.	(+) Takes advantage of conditions before climate changes dramatically
	9.2— Favor or restore native species that are expected to be better adapted to future conditions	Natural regeneration of white pine and red pine could be promoted where present. Other native seed and stock could also be used to promote native species diversity. Mixed	

		plantations have been established in MABI's past and could be established again with native species. White pine and red spruce could be inter-planted with future adapted hardwood species (namely oak and hickory)	
	9.4 — Emphasize drought-tolerant species and populations	Where plantation species are replanted, use stock from heat- and drought-adapted populations (e.g., from southern Europe)	(-) Native species like red spruce are expected to decline on some sites.
	9.5 — Guide species composition at early stages of stand development	Encourage plantations species at early stages with weeding and thinning. Natural regeneration that is desirable and free to grow could be retained within plantations to increase diversity within stands.	

ADAPTATION STRATEGY	ADAPTATION APPROACH	ADAPTATION TACTICS	BENEFITS OR DRAWBACKS/BARRIERS
Plantations transition to northern hardwood systems over time			
Strategy 1: Sustain fundamental ecological function	1.4 – Reduce competition for moisture, nutrients, and light	Begin to allocate more resources to younger cohorts to promote the establishment of a second age-class	(+) Regeneration harvests are currently underway
Strategy 2: reduce the impacts of biological stressors	2.2 – Prevent the introduction and establishment of invasive plant species and remove existing invasive species	Continue on-going efforts to monitor stands for presence and abundance of invasive species and continue the annual removal of identified patches of established invasive species.	(+) Currently underway

	2.3 – Manage herbivory to promote regeneration of desired species	Monitor forest for browse impacts and potential impacts invasive earth worm on regeneration (primarily sugar maple). Herbivory currently does not seem to be posing a major threat to regeneration but this could change.	(+) Use current monitoring efforts to track potential impacts of herbivory
Strategy 3: Reduce the risk of long-term impacts of severe disturbance	3.3 – Alter forest structure to reduce severity and or extent of wind and ice damage	Select mature trees for retention that are vigorous and wind firm with live crown ratios of 30% or greater if possible. Retained legacy trees could be grouped to limit potential wind damage.	
Strategy 5: Maintain and enhance species and structural diversity.	5.1 — Promote diverse age classes	Use un-even aged silvicultural approaches to regenerate new cohorts at each entry. Retain some overstory trees past economic rotation age.	
	5.2 – Maintain and restore diversity of native species	Use regeneration harvests to establish a mix of native hardwood and softwood species.	
Strategy 9: Facilitate community adjustments through species transitions.	9.1— Anticipate and respond to species decline	Thin stands to improve vigor and reduce risks from drought	(+) Many stands can have one additional thinning before end of rotation (+) Above also provides opportunity to try new ideas and further assess climate change impacts (-) Some plantation stands designated for transition appear to show slow growth in overstory trees so thinning might not have a large impact of tree vigor
	9.2— Favor or restore native species that are expected to be better adapted to future conditions	Establish desired native species in the near-term (next 2 decades). Continue to promote native regeneration through regeneration harvests.	(+) Regeneration phase may be more sensitive to climate change than established large saplings/trees

	9.5 — Guide species composition at early stages of stand development	Allow for natural regeneration of native plants in old plantations.	(-)Where established, beech will compete with desired species
	9.7 — Establish or encourage new mixes of native species	Utilize larger gap sizes to encourage a greater diversity of native regeneration. Retain and promote conifer component to establish mixed hardwood stands in the future.	(-) Aesthetics are a concern with larger gap sizes. Some visitors may not like large openings ('messy conditions').
	9.7 — Establish or encourage new mixes of native species	Encourage existing species projected to do well on sites (oaks, hickory, white pine, red spruce). Where future adapted species are not present on site or present but at less than optimal stocking levels, look to enrich with planting.	(+) Future adapted species exist on site. (-) Enrichment plantings do require additional resources

Table 15: Adaptation tactics table for plantation forest system

Hemlock-Hardwood Forest System: Adaptation Tactics

Adaptation Tactics			
Hemlock-Hardwood Forest System			
ADAPTATION STRATEGY	**ADAPTATION APPROACH**	**ADAPTATION TACTICS**	**BENEFITS OR DRAWBACKS/BARRIERS**
Strategy 1: Sustain fundamental ecological function	1.2-3 – Reduce impacts to soils and nutrient cycling. Maintain or restore hydrology. Maintain or restore riparian areas	Riparian areas characterized by mature hemlock trees currently. These areas might be at risk of losing ecological function if hemlock is lost due to HWA related decline and mortality. Special attention may need to be given to establish new cohorts along waterways or introduce species that may	(-) Riparian areas are difficult to work in due to their sensitive nature and are subject to additional environmental regulation and oversight.

		fill similar ecological roles as hemlock. Stream health could be monitored, with a focus on temperature and invertebrate diversity.	
Strategy 2: Reduce the impacts of biological stressors	2.1 — Maintain or improve the ability of forests to resist pests and pathogens	Increase early detection and monitoring efforts and partner with other organization/volunteers where possible. Main pest of concern at this time is the Hemlock woolly adelgid	(+)Leverage existing efforts by Forest Service and Vermont Agency of Natural Resources. (+)Local volunteers could be trained as early detection agents
	2.1 — Maintain or improve the ability of forests to resist pests and pathogens	Thin hemlock stands to increase vigor and reduce susceptibility to HWA. Recent research suggests that silvicultural thinning to increase light exposure to hemlock trees can reduce adelgid abundance and improve C balance when the tree is infested (Brantley et al. 2017).	(+) Thinning could be done as a part of a planned regeneration harvest (-) Many of the hemlock trees are located in areas that a difficult to access and thinning (+/-) Thinning could be done with using a single feller and thinned trees could be left on-site to increase downed woody material within stands. The drawback is that there would be no financial return from the harvest.
	2.2 – Prevent the introduction and establishment of invasive plant species and remove existing invasive species	Continue on-going efforts to monitor stands for presence and abundance of invasive species and continue the annual removal of identified patches of established invasive species.	(+) Currently underway
	2.2 – Prevent the introduction and establishment of invasive plant species and remove existing invasive species	Explore the use of biological control or targeted use of insecticide on highly valued hemlock trees.	(-) There is currently not a lot of information on the efficacy of these measures (+) Could maintain highly valuable specimens on-site

Strategy 4: Maintain or create refugia	4.3 – Establish reserves for at-risk and displaced species	Hemlock trees found on slightly enriched sites or areas where hemlock regeneration is present could be retained as reserves. This will preserve any natural resistance that might be present.	
Strategy 5: Maintain and enhance species and structural diversity	5.1 – Promote diverse age classes	Use regeneration harvests to establish new cohorts while tending to existing age classes.	(+) These mixed stands contain a diversity of overstory species in select locations and many of these stands already have multiple age-classes present (-) Silvicultural treatments may be cost prohibitive due to accessibility issues and lack of marketability of existing acceptable growing stock.
	5.2 – Maintain and restore diversity of native species	The use of regeneration harvesting coupled with reserve areas could be used to restore diversity in younger age-classes and maintain diversity in the overstory.	(-) There are lower financial incentives for harvesting in hemlock dominated areas
	5.3 – Retain biological legacies	Large and old tree densities are currently high within these stands and therefore these existing characteristics can be retained.	(-) Some of the largest trees present on site are at risk of future mortality due to hemlock woolly adelgid introduction.
	5.4 – Establish reserves to maintain ecosystem diversity	Reserve areas could be identified and delineated. Some areas within this forest system are well suited for reserve establishment given their late successional condition. Reserve areas could vary in size and location. Area based goals could be established for reserves across the entire forest system.	(+) Stands are structural diverse, have the highest biomass storage currently, and are some of the oldest stands in MABI

Strategy 6: Increase ecosystem redundancy across the landscape	6.2 – Maintain the boundaries of reserves to increase diversity	Existing reserve areas could be expanded. Existing buffers around riparian areas could be expanded.	
Strategy 8: Maintain and enhance genetic diversity	8.2 – Favor existing genotypes that are better adapted to future conditions	Identify areas where representation of yellow birch, red/white oak, red maple, and white pine and red spruce can be increased. These species are present currently within these stands and could enhance the over adaptive capacity of the stand if promoted.	(+) These identified species are present on-site
Strategy 9: Facilitate community adjustments through species transitions.	9.1— Favor or restore native species that are expected to be adapted to future conditions	On sites where overstory advance regeneration is present or were overstory trees that are desirable and well adapted to future conditions are present, use regeneration harvesting to promote regeneration.	(-) Harvests in these stands may not have high commercial value
	9.2 – Establish or encourage new mixes of native species	Representation of desirable hardwood species such as red oak and yellow birch (including red maple which is desirable due to its high adaptability) can be increased where these species are present in overstory or where advanced regeneration is present.	
	9.7 – Introduce species that are expected to be adapted to future conditions	Successor species to hemlock should be identified. Red spruce has been suggested as a potential successor species that could be under planted within hemlock stands. Black birch could also be considered. Special focus should be given to riparian areas where hemlock plays an important role regulating water temperature. Additional promoting a	

		softwood component in these stands will retain the deep shade conditions in the heat of the summer and the reduced snow pack in the winter which provides habitat for a suite of native species.	

Table 16: Adaptation tactics table for hemlock-hardwood forest system in the Mount Tom Forest

Culturally and Ecologically Significant Areas: Adaptation Tactics

Adaptation Tactics			
Culturally and Ecologically Significant Areas			
ADAPTATION STRATEGY	**ADAPTATION APPROACH**	**ADAPTATION TACTICS**	**BENEFITS OR DRAWBACKS/BARRIERS**
Carriage Roads			
Strategy 1: Sustain fundamental function	1.1 — Maintain or restore soil quality and nutrient cycling	Continue maintenance of roads, culverts, and other infrastructure	(+) Road crowning, ditch cleaning, regular maintenance and other practices reduce risks from extreme events
	1.2 — Maintain or restore hydrology		(-) May cost more in future
Legacy Trees			
Strategy 8: Maintain and enhance genetic diversity	8.2 — Favor existing genotypes that are better adapted to future conditions	Retain oak legacy trees and use as a seed source for future regeneration efforts	
Strategy 9: Facilitate community adjustments through species transitions.	9.2— Favor or restore native species that are expected to be better adapted to future conditions	Identify trees for retention along major road ways based on their current vigor and their projected future adaptability to changing growing conditions and disturbances.	
Significant Ecological Areas: Wildlife habitat, wetlands, waterways			

Strategy 1: Sustain fundamental ecological function	1.3. Maintain or restore riparian areas	Increase buffers where acceptable and look to encourage or introduce a successor species for hemlock along waterways	
Strategy 4: Maintain or create refugia	4.1. Prioritize and maintain unique sites.	Create and increase buffer zones around identified important wildlife habitat. Identify unique and or enriched sites which could promote higher species diversity to include within reserve areas	(-) Enriched sites can also be your most productive sites for growing merchantable timber, creating a potential trade off.
	4.2. Prioritize and maintain sensitive or at-risk species or communities		
Strategy 5: Maintain and enhance species and structural diversity.	5.4. Establish reserves to maintain ecosystem diversity	Identify areas where reserves can be established across forest systems	

Table 17: Adaptation tactics table for culturally and ecologically significant areas

Chapter 7: Monitor and Re-Evaluate

Monitor

Once management decisions have been made and adaptive tactics have been conducted the final step in the adaptive management process begins. The continued monitoring of management actions is critical to the adaptive management process. Given the uncertainty around the timing and impact of future changes, monitoring and evaluating the effectiveness of actions in meeting desired outcomes is as important as selecting appropriate management tactics.

We outline below monitoring benchmarks that can be used to evaluate the effectiveness of management actions as it relates to achieving the desired future condition for each forest system. We also highlight the means by which these monitoring efforts can be implemented.

Northern Hardwood Forest System: Monitoring Table

Long-Term Management Goal	Monitoring Benchmark	Implementation
Maintain a diversity of desirable tree species	Maintain at least 3 desirable species, **each** representing 10% of basal area in all age-classes.	Use forest inventory (conducted every 5 years) to determine Trees Per Acre (TPA) and Basal Area and assess importance values of desirable species in each size class (sapling, pole, saw). **If** there are not at least 3 desirable species each representing 10% of composition, identify species present on site to encourage in next management cycle. Continued use of forest inventory to assess progress
Establish a diverse uneven-aged forest	Sapling densities of desirable species are **sufficient** when maintained at levels equal to or greater than 150 individuals/acre and **optimal** when maintained at levels equal to or greater than 350 trees/acre.	Use forest inventory to determine Trees Per Acre (TPA) of desirable saplings. Desirable species can be determined based on economic value and or adaptability to projected future stressors.

Establish a diverse uneven-aged forest	Seedling densities of desirable species are **sufficient** when maintained at levels equal to or greater than 600 individuals/acre and **optimal** when maintained at levels equal to or greater than 1,000 individuals/acre	Use forest inventory to determine Trees Per Acre (TPA) of desirable saplings. Desirable species can be determined based on economic value and or adaptability to projected future stressors.
Increase resistance to common and novel disturbances	Invasive species are identified and controlled where possible	Continued invasive species detection, monitoring, and removal
Increase resistance to common and novel disturbances	Maintain stands at desirable stocking levels based on the Northern Hardwoods Stocking Guide (NE-603: Leak et al. 1987).	Continued forest inventory to determine stand level TPA,BA, QMD, and Diameter distributions etc.
Maintain and enhance resilience to common and novel disturbances	Promote and increase diversity in species composition, age classes, structural components of the forest, and adaptation responses (abilities) present within in dominant species. Species diversity (Shannon's index) should be maintained or increased across size classes. Three or more age classes should be present within 20 years. Standing dead trees are equal to or greater than 5 trees per acre and downed woody material is recruited at each harvest entry. Maintain or increase weighted adaptability scores across size classes.	Use forest inventory data and regeneration surveys to assess species diversity, number of established age classes, abundance of structural components like standing dead tree

Promote forest transition to increase adaptive capacity in the face of projected environmental change	Establish and increase representation of species identified as highly adapted to future forest conditions. Identify species already established on site (northern red oak) and look to increase the representation of the species where possible. Identify 2-3 species that are underrepresented or not present on site but are projected to gain suitable habitat in the future to test as potential enrichment planting species.	Use inventory to assess compositional shifts in future adapted species abundance (i.e. monitor red oak regeneration success). Conduct surveys of planted species 1 and 3 years after planting. **IF** stocking falls below 150 stems/acre consider replanting.
Retain large trees as biological and cultural legacies	Maintain 5 large trees (DBH > 24-inches) per/acre especially along recreational trails	Use forest inventory and visual survey to identify existing large trees and begin monitoring. Identify large trees to recruit as legacies at each 5-year inventory cycle
Provide high quality wildlife habitat	Retain and recruit snags. Maintain 5 snags/acre and look in to increase where possible	Use forest inventory and visual survey to identify existing large trees and begin monitoring. Identify large trees to recruit as legacies at each 5-year inventory cycle
Provide high quality wildlife habitat	Maintain a small percentage of the total area as permanent reserves	Identify areas already serving as reserves and new areas well suited for reserve areas. Delineate areas on the ground. Establish monitoring plots within reserves if they do not already exist.

Table 18: Adaptive management monitoring table for northern hardwood forest system in the Mount Tom Forest

Plantation Forest System: Monitoring Table

Long-Term Management Goal	Monitoring Benchmark	Implementation
Maintain healthy plantations that are resistant to existing and novel stressors	Greater than 50% of overstory trees are of acceptable growing stock (AGS) with live crown ratios equal to or greater than 30%. Stocking is maintained at desirable levels to ensure adequate growing space to overstory trees	Use forest inventory to asses AGS/UGS and average live crown ratios for stands maintained as plantations.
Maintain healthy plantations that are resistant to existing and novel stressors	Regeneration efforts promote the establishment of new plantation species. Planting is conducted where needed to ensure sufficient stocking in the regeneration layer.	Conduct regeneration surveys 1 and 3 years post-harvest and or planting
Maintain healthy plantations that are resistant to existing and novel stressors	Monitor health of overstory trees and identify potential pest and pathogen stressors	Use 5-year forest inventory to assess health of existing plantations and employ early detection monitoring for pest and pathogens
In designated areas transition plantations and establish a diverse uneven-aged forest (3 or more age classes established) mixed northern hardwood forest	Increase desirable mix of native species (or naturally regenerated species?) on select sites to a level equal to or greater than 30% of composition	Use forest inventory (conducted every 5 years) to determine Trees Per Acre (TPA) and Basal Area and assess importance values of desirable hardwood and softwood species in each size class (sapling, pole, saw). As these sites transition focus should be directed towards the smaller size classes. Assess saplings and pole size classes for desirable representation.

In designated areas transition plantations and establish a diverse uneven-aged forest (3 or more age classes established) mixed northern hardwood forest	Sapling densities of desirable species are **sufficient** when maintained at levels equal to or greater than 150 individuals/acre and **optimal** when maintained at levels equal to or greater than 350 trees/acre.	Use forest inventory to determine Trees Per Acre (TPA) of desirable saplings. Desirable species can be determined based on economic value and or adaptability to projected future stressors.
In designated areas transition plantations and establish a diverse uneven-aged forest (3 or more age classes established) mixed northern hardwood forest	Seedling densities of desirable species are **sufficient** when maintained at levels equal to or greater than 600 individuals/acre and **optimal** when maintained at levels equal to or greater than 1,000 individuals/acre	Use forest inventory to determine Trees Per Acre (TPA) of desirable saplings. Desirable species can be determined based on economic value and or adaptability to projected future stressors.
Increase resistance to common and novel disturbances	Invasive species are identified and controlled where possible	Continued invasive species detection, monitoring, and removal
Increase resistance to common and novel disturbances	Maintain stands at optimal stocking levels.	Continued forest inventory to determine stand level TPA,BA, QMD, and Diameter distributions etc.
Maintain and enhance resilience to common and novel disturbances	Promote and increase diversity in species composition, age classes, structural components of the forest, and adaptation responses (abilities) present within in dominant species. Species diversity (Shannon's index) should be maintained or increased across size classes. Three or more age classes should be present within 20 years. Standing dead trees are equal to or greater than 5 trees per acre and downed woody material is recruited at each harvest entry. Maintain or increase weighted adaptability scores across size classes.	Use forest inventory data and regeneration surveys to assess species diversity, number of established age classes, abundance of structural components standing dead tree

Promote forest transition to increase adaptive capacity in the face of projected environmental change	Establish and increase representation of species identified as highly adapted to future forest conditions. Identify species already established on site (northern red oak) and look to increase the representation of the species where possible. Identify 2-3 species highly underrepresented or those that are not present on site but are projected to gain suitable habitat in the future to test as potential enrichment planting species. Within plantation stands look to growing stock that is tolerant or resistant to projected environmental changes including but not limited to increased temperature and drought stress.	Use inventory to assess compositional shifts in future adapted species abundance (i.e. monitor red oak regeneration success). Conduct surveys of planted species 1 and 3 years after planting. IF stocking falls below 150 stems/acre consider replanting.
Retain large trees as biological and cultural legacies	Maintain 5 large trees (DBH > 24 inches) per/acre within stands and along recreational trails	Use forest inventory and visual survey to identify existing large trees and begin monitoring. Identify large trees to recruit as legacies at each 5-year inventory cycle
Provide high quality wildlife habitat	Retain and recruit snags. Maintain 5 snags/acre and look in to increase where possible	Use forest inventory and visual survey to identify existing large trees and begin monitoring. Identify large trees to recruit as legacies at each 5-year inventory cycle

Table 19: Adaptive management monitoring table for plantation forest system in the Mount Tom Forest

Hemlock-Hardwood Forest System: Monitoring Table

Long-Term Management Goal	Monitoring Benchmark	Implementation
Maintain a diversity of desirable tree species	Maintain at least 3 desirable species each representing 10% or greater of basal area in all age-classes.	Use forest inventory (conducted every 5 years) to determine Trees Per Acre (TPA) and Basal Area and assess importance values of desirable species in each size class (sapling, pole, saw). **If** there are less than 3 desirable species above 10% of composition, identify species present on site to encourage in next management cycle. Continued use of forest inventory to assess progress
Establish a diverse uneven-aged forest	Sapling densities of desirable species are **sufficient** when maintained at levels equal to or greater than 150 individuals/acre and **optimal** when maintained at levels equal to or greater than 350 trees/acre.	Use forest inventory to determine Trees Per Acre (TPA) of desirable saplings. Desirable species can be determined based on economic value and or adaptability to projected future stressors.
Establish a diverse uneven-aged forest	Seedling densities of desirable species are considered **optimal** when maintained at levels equal to or greater than 1,000 individuals/acre	Use forest inventory to determine Trees Per Acre (TPA) of desirable saplings. Desirable species can be determined based on economic value and or adaptability to projected future stressors.
Increase resistance to common and novel disturbances	Develop response plan to HWA	Assess rate of HWA movement in the region and develop a set of management guidelines to be used before and after HWA is detected
Increase resistance to common and novel disturbances	Monitor movement of HWA in region and assess Hemlock trees on site for signs of HWA presence	Annual monitoring of Hemlocks can be done with a visual walk through survey every year. If HWA is detected consult response plan
Increase resistance to common and novel disturbances	Invasive species are identified and controlled where possible	Continued invasive species detection, monitoring, and removal
Increase resistance to common and novel disturbances	Maintain stands at optimal stocking levels based appropriate stocking guide	Continued forest inventory to determine stand level metrics. Identify

	(Leak et al. 1987). Identify healthy vigorous hemlock for release with thinning on 3-4 sides.	5-10 Hemlock trees/acre to release with thinning.
Maintain and enhance resilience to common and novel disturbances	Promote and increase diversity in species composition, age classes, structural components of the forest, and adaptation responses (abilities) present within in dominant species. Species diversity (Shannon's index) should be maintained or increased across size classes. Three or more age classes should be present within 20 years. Standing dead trees are equal to or greater than 5-7 trees per acre and downed woody material is recruited at each harvest entry. Maintain or increase weighted adaptability scores across size classes.	Use forest inventory data and regeneration surveys to assess species diversity, number of established age classes, abundance of structural components such as standing dead trees
Promote forest transition to increase adaptive capacity in the face of projected environmental change	Establish and increase representation of species identified as highly adapted to future forest conditions. Identify species already established on site (northern red oak) and look to increase the representation of the species where possible. Identify 2-3 species highly underrepresented or those that are not present on site but are projected to gain suitable habitat in the future to test as potential enrichment planting species.	Use inventory to assess compositional shifts in future adapted species abundance (i.e. monitor red oak regeneration success). Conduct surveys of planted species 1 and 3 years after planting. IF stocking falls below 150 stems/acre consider replanting.

Retain large trees as biological and cultural legacies	Maintain 10 or more large trees (DBH > 24 inches) per/acre especially along recreational trails	Use forest inventory and visual survey to identify existing large trees and begin monitoring. Identify large trees to recruit as legacies at each 5-year inventory cycle
Provide high quality wildlife habitat	Retain and recruit snags. Maintain 5 snags/acre and look in to increase where possible	Use forest inventory and visual survey to identify existing large trees and begin monitoring. Identify large trees to recruit as legacies at each 5-year inventory cycle
Provide high quality wildlife habitat	Maintain and or establish reserve areas if desired	Identify areas well suited for reserve areas. Delineate areas on the ground. Establish monitoring plots within reserves if they do not already exist.

Table 20: Adaptive management monitoring table for hemlock-hardwood forest system in the Mount Tom Forest

Re-Evaluate

One means of evaluating the potential outcomes of current management is to use forest landscape simulation models. In the next chapter we will present the results from a forest landscape simulation effort. These simulations can be used to evaluate projected long-term impacts a changing climate and alternative management.

Chapter 8: Future forest projections

Given the unprecedented changes that are occurring and are projected to occur across our region, resource managers will have to contend with novel environmental conditions and disturbance regimes today and in the future. Resource managers have historically relied on concepts of historic and natural range of disturbance variability and ecological sustainability to inform management decisions. While these concepts remain valuable, we can no longer rely solely on past forest conditions to inform future management. As an alternative, managers have begun focusing on increasing the level of functional responses in a given forest, as detailed in the previous chapters, and are beginning to rely on forest landscape simulation and climate envelope models as decision support tools for understanding the outcomes of different management regimes and climate projections on future forest conditions. Models such as forest landscape simulators should not be used as forecasts, however, they can provide qualitative insights into the range of future changes under different climate scenarios and management regimes (Millar et al., 2007).

The use of spatially explicit forest landscape simulation models such as LANDIS-II, have been utilized in recent years as means of providing fine-scale projections of future forest compositional and functional changes (Duveneck & Scheller, 2015, 2016; Duveneck et al., 2014; Ravenscroft, Scheller, Mladenoff, & White, 2010; Scheller et al., 2007). Outputs from these models in combination with feedback from scientists and resource managers have served as a central element in developing forest vulnerability assessments for much of the eastern US (M. K. Janowiak, L. Iverson, D.J. Mladenoff, E. Peters, K.R. Wythers, W. Xi, L.A. Brandt, et al. , 2014).

We have adapted the landscape simulation model to assist in the evaluation of specific management decisions at MABI. We used LANDIS-II to simulate forest growth and development under three projected climate change scenarios and three management regimes. LANDIS-II (v6.0) is a spatially explicit forest landscape simulation model (Scheller et al., 2007) that simulates forest successional dynamics, seed dispersal, and response to disturbances such as windthrow and harvesting (Ravenscroft et al., 2010; Scheller et al., 2007). Biomass accumulation and decomposition are also simulated in this model (Scheller et al. 2007). These successional dynamics and ecosystem processes are expressed within a representative landscape of interacting cells laid out in a grid. Each cell in this study is 30x30 meters and all cells are grouped together into blocks or ecoregions based on similar features such as soil type, topography, or dominant vegetation type. Multiple combinations of species-by-age cohorts exist within each cell and contain spatially relevant data related to species biomass and age (Duveneck & Scheller, 2015; Duveneck et al., 2014; Ravenscroft et al., 2010).

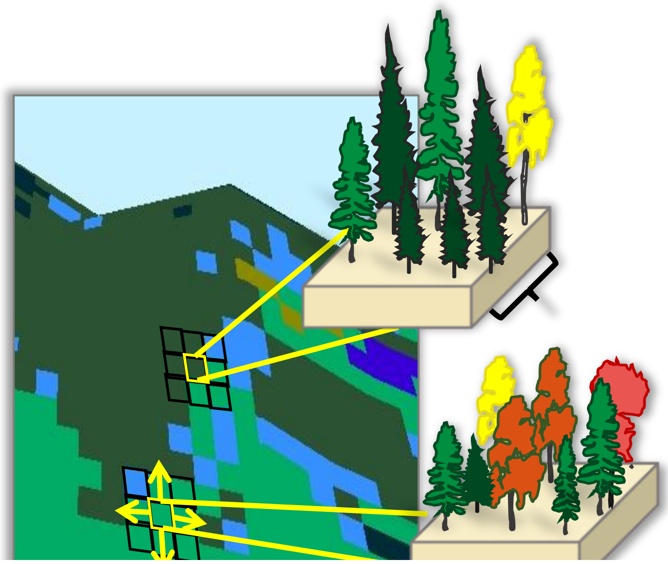


Figure 8: Visual representation of LANDIS landscape of grid cells populated by tree species of individual age cohorts.

An initial tree composition for MABI and surrounding landscape were derived from Landsat forest classification and pixel reflectance data (Ravenscroft et al., 2010). Forest inventory data from MABI was used to parameterize the forest classification process. We simulated forest growth for two-hundred (200) years at five-year consecutive time steps. We utilized the following extensions to the LANDIS-II core framework: Biomass Succession (v3.1), Biomass Harvest (v2.1), Biomass Insects (v2.0), and Base Wind (v2.0) (Duveneck & Scheller, 2016).

To simulate the long-term impacts of forest management decisions we utilized the Biomass Harvest (v2.1) extension for LANDIS-II. This extension allowed us to simulate specific harvesting approaches across MABI. These management approaches were simulated under three projected climate conditions. These climate conditions are: a continuation of current climate conditions and two different climate scenarios representing modest and large increases in greenhouse gas concentrations. Together, these three climate scenarios represent a range of potential future climate conditions for the region.

Simulating Long-Term Impacts of Current and Alternative Management

Three different management regimes were used for this study (Table 20). The first management approach seeks to maintain diversity while promoting a forest which is resistant to common stressors. We call this management regime, **Alternative *1: Resistance and Resilience***. Alternative 1 is modeled after past and current management at MABI. The second management regime is called ***Alternative 2: Increased Resilience*** and seeks to increase the diversity of species and age structures present at MABI. When compared to Alternative 1, Alternative 2 promotes an increased reliance on regeneration harvests which create larger forest openings. The greater application of group selection harvesting in Alternative 2 is designed to promote greater species diversity overtime by promoting the regeneration tree species with a wider range of light requirements. The third management regime is called ***Alternative 3: Resilience and Transition (RT)*** and aims to increase compositional complexity (resilience) while increasing adaptive capacity by promoting a greater

representation of "future adapted" species. Tree species that have been identified as having the life history attributes suited for projected future climate conditions were promoted through a mix of simulated regeneration harvests and intermediate treatments. Red oak, yellow birch, and red maple are examples of tree species that are projected to be well adapted to future forest conditions and were therefore, these species were retained at higher rates during simulated harvests. In addition to using regeneration harvests to increase representation of future adapted tree species, a set of tree species were selected for planting following the simulated harvests. The trees that were planted are native to the region, are found locally, and are projected to respond well to increased temperatures and changing precipitation regimes as shown in vulnerability assessments for the region (Duveneck & Scheller, 2015; Iverson, Prasad, & Matthews, 2008). For this simulation we have selected hardwood species including northern red oak, white oak, black birch, black cherry, bitternut hickory, and shagbark hickory. The planting of conifers was also simulated and these species included red spruce and white pine.

Alternative Management Tactics

Alternative 1: Resistance and Resilience

- **Single tree selection:** Single tree selection is used on a wide range of sites in Northern Hardwood and Hemlock-Hardwood forest types throughout MABI. Harvest aim to regenerate primarily shade-tolerant species using a dispersed network of small canopy opening on 20-year cutting cycle. 20% of overstory removed at each entry. Stands with high component of sugar maple and ash are treated preferentially.
- **Group selection:** Group selection is used within all forest systems with the goal of regenerating both shade tolerant and mid-tolerant species. This alternative management regime uses group selection to create canopy openings that are 0.25-0.50-acres in size. This treatment is conducted on a 20-year cutting cycle and is typically located on sites where beech is more prevalent.

- **Intermediate thinning**: 30-40% of overstory removed at each entry. Applied with all forest systems as a means of managing the existing overstory.
- **Shelterwood:** Applied with plantation forest systems. Harvests remove 40% of mature age classes upon first entry followed by an overstory removal cutting (80-90% removal) 25-years following the initial establishment cutting.

Alternative 2: Increased Resilience

- **Single tree selection:** Single tree selection is used within Northern Hardwood and Hemlock-Hardwood forest types. Harvest aim to regenerate primarily shade-tolerant species using a dispersed network of small canopy opening on 20-year cutting cycle. 20% of overstory removed at each entry. Stands with high component of sugar maple and ash are treated preferentially. Single tree selection is applied to a lesser extent than is applied under **Alternative 1.**
- **Group selection:** Group selection is the most common treatment type in this alternative and is applied within all forest systems with the goal of regenerating both shade tolerant and mid-tolerant species. This alternative management regime uses group selection to create canopy openings that are 0.25-1.0-acres in size. This treatment is conducted on a 20-year cutting cycle and is typically located on sites where beech is more prevalent.
- **Patch selection**: Group selection harvests which create larger openings 1-4 acres in size. Applied within plantation forest system stands which have reached maturity.
- **Shelterwood:** Applied with plantation forest systems. Harvests remove 40% of mature age classes upon first entry followed by an overstory removal cutting (80-90% removal) 25-years following the initial establishment cutting.
- **Intermediate thinning**: 30-40% of overstory removed at each entry. Applied with all forest systems as a means of managing the existing overstory.

Alternative 3: Resilience and Transition

- **Single tree selection:** Single tree selection is used within Northern Hardwood and Hemlock-Hardwood forest types. Harvest aim to regenerate primarily shade-tolerant species using a dispersed network of small canopy opening on 20-year cutting cycle. 20% of overstory removed at each entry. Stands with high component of sugar maple and ash are treated preferentially. Single tree selection is applied to a lesser extent than is applied under **Alternative 1** and **Alternative 2.**
- **Group selection:** Group selection is the most common treatment type in this alternative and is applied within all forest systems with the goal of regenerating both shade tolerant and mid-tolerant species. This alternative management regime uses group selection to create canopy openings that are 0.25-1.0-acres in size. This treatment is conducted on a 20-year cutting cycle and is typically located on sites where beech is more prevalent.
- **Group selection + climate suitable planting:** Group selection harvests are applied within all forest systems with the goal of regenerating both shade tolerant and mid-tolerant species. This alternative management regime uses group selection to create canopy openings that are 0.25-1.0-acres in size. This treatment is conducted on a 20-year cutting cycle and is typically located on sites where beech is more prevalent. Unlike the traditional group selection harvests used in **Alternative 1 and 2,** this treatment simulates the planting of tree seedlings following the harvest. Northern red oak, white oak, black cherry, black birch are the primary species planted. A small proportion of the plantings occur within old plantations were white pine and red spruce are planted.
- **Patch selection**: Group selection harvests which create larger openings 1-4 acres in size. Applied within plantation forest system stands which have reached maturity.
- **Shelterwood:** Applied with plantation forest systems. Harvests remove 40% of mature age classes upon first entry followed by an overstory removal cutting (80-90% removal) 25-years following the initial establishment cutting.
- **Intermediate thinning**: 30-40% of overstory removed at each entry. Applied with all forest systems as a means of managing the existing overstory.

Table 21: Silvicultural treatments simulated in each alternative.

Climate change was simulated within the model using NASA Earth Exchange (NEX) downscaled (800m resolution) climate projection models, which were derived from the General

Circulation Model (GCM) runs developed for the Fifth Assessment Report for the Intergovernmental Panel on Climate Change (IPCC) (Moss et al., 2010). We utilized the MPI-ESM-LR and two Representative Concentration Pathways (RCP 4.5 and RCP 8.5) to represent the potential future climate conditions for the years 2006-2099 (Figure 9). Current climate was derived from historic PRISM climate data for the region from 1900-2017 (Daly et al., 2008).

In order to illustrate the variability in the climate models used in this report, we highlight the average annual July temperature and total annual precipitation each year in the simulation under high (RCP-8.5) and low (RCP-4.5) emissions scenarios. Under high the emissions scenario mean July temperature is projected to increase by 6.8°C (Figure 9) and total annual precipitation is projected to increase by 19.09cm (Figure 9). Under the low emission scenario mean July temperature is projected to increase by 2.28°C (Figure 9) but total annual precipitation is not projected to change dramatically (Figure 9).

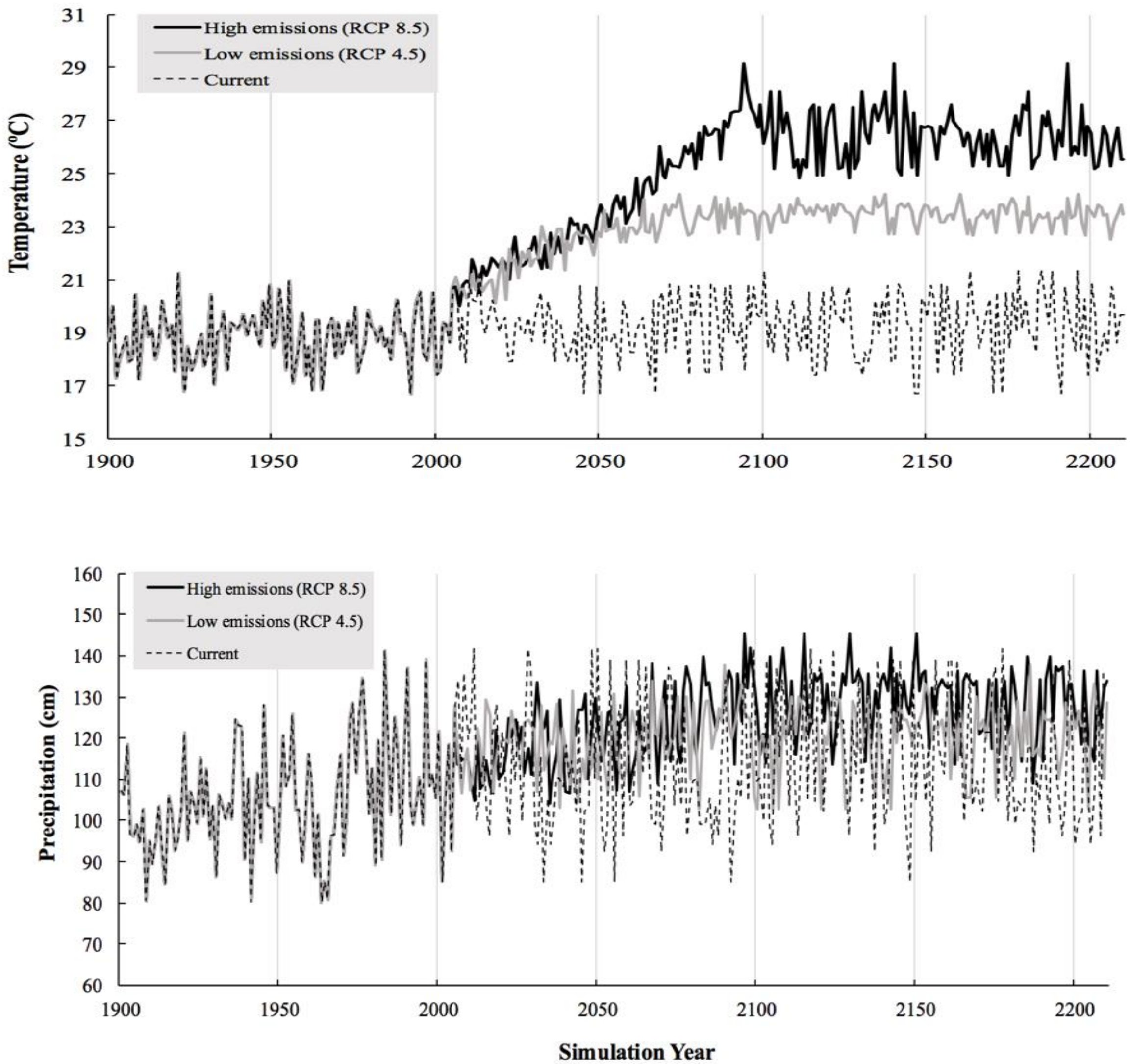


Figure 9: Mean July temperature (Top) and average annual precipitation (bottom) under current climate and two RCPs (4.5 and 8.5). Current climate for the period of 2017-2210 is based on a random sample of mean July temperature and average annual precipitation from 30 years prior to 2017.

Current forest tree species composition was determined using the 2017 forest inventory data collected at 144 plots throughout MABI (Figure 10). To evaluate changes in species composition overtime under different management and climate scenarios, we compared the current forest composition at MABI with the projected future composition for simulation year 2068, 2118, 2218. Forest composition was determined by reclassifying each 30x30 meter cell in the simulation landscape to show the species or species group which comprised the majority of the above ground biomass. By reclassifying the landscape in this way, we were able to summarize changes in the percent of forest land at MABI that was dominated by key tree species and species groups (Figure 10).

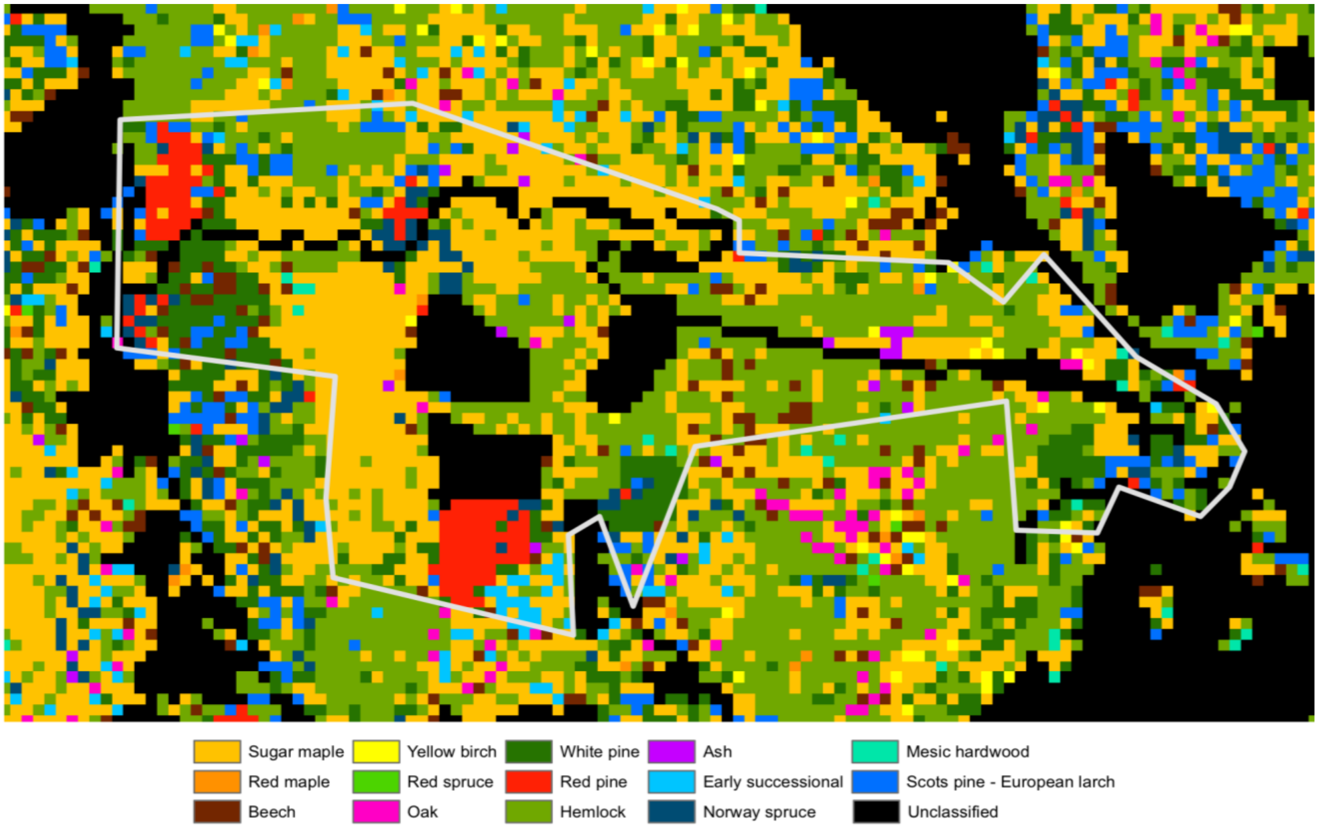


Figure 10: Map of initial forest community type based on dominant species within each 30x30 meter cell. Sugar maple, beech, yellow birch, white pine, hemlock (*Tsuga canadensis),* Norway spruce, and red pine are all dominated by the single species. The other forest types are comprised of tree species groups. Early successional: *Prunus pensylvanica*, *Prunus serotina*, *Betula papyrifera*, *Populus grandidentata*, *Populus tremuloides*; Mesic – Hardwood: *Fraxinus americana*, *Tilia americana*, *Quercus alba*, *Betula lenta;* Scots pine – European larch: *Pinus sylvestris and Larix decidua*. Cells are reclassified to show the forest type with the highest total biomass

Results

Sugar maple is currently the dominant species (accounts for the highest above ground biomass per unit area) on 37.4% of forest land at MABI. Eastern hemlock is dominant on 32.8% of the forest area. White pine, American beech, yellow birch, white ash, and red pine are all commonly found but comprise a lesser component of the tree species composition. Oak species currently comprise 0.4% of the forest area (Table 22).

Climate	Management	Year	Sugar maple	Red maple	American beech	Yellow birch	Red spruce	Oak	White pine	Red pine	Eastern hemlock	White ash	Early successional	Norway Spruce	Mesic hardwood	Plantation species
		2018	37.4%	0.1%	3.0%	0.6%	0.0%	0.4%	11.0%	5.6%	32.8%	0.8%	1.1%	2.6%	0.5%	4.1%
Current	*Alternative 1*	2068	48.6%	0.1%	5.8%	1.2%	0.1%	0.9%	10.6%	4.8%	24.1%	0.7%	0.4%	1.3%	0.3%	1.1%
Current	*Alternative 2*	2068	43.8%	0.2%	3.4%	2.6%	0.3%	2.0%	8.1%	3.1%	22.1%	1.2%	4.3%	1.3%	0.4%	7.2%
Current	*Alternative 3*	2068	45.5%	0.3%	4.5%	2.9%	0.4%	1.7%	7.9%	5.5%	24.1%	0.9%	1.2%	0.8%	0.2%	3.8%
Current	*Alternative 1*	2118	34.9%	0.5%	6.5%	2.1%	0.6%	1.7%	10.8%	3.6%	32.5%	0.4%	0.7%	1.7%	0.1%	3.8%
Current	*Alternative 2*	2118	42.6%	0.2%	5.4%	3.5%	0.9%	2.2%	9.3%	1.4%	20.1%	0.7%	4.0%	2.5%	0.2%	7.0%
Current	*Alternative 3*	2118	37.5%	0.5%	6.0%	4.2%	0.7%	3.1%	9.1%	5.6%	23.3%	0.3%	2.0%	1.1%	0.2%	6.3%
Current	*Alternative 1*	2218	33.0%	0.0%	3.1%	3.4%	4.6%	3.3%	5.6%	1.1%	34.9%	0.7%	0.3%	3.8%	0.3%	5.8%
Current	*Alternative 2*	2218	39.5%	0.0%	3.0%	4.5%	3.4%	3.6%	5.3%	1.2%	24.7%	0.8%	0.5%	6.7%	0.2%	6.8%
Current	*Alternative 3*	2218	31.3%	0.1%	2.2%	7.0%	3.6%	7.1%	6.9%	0.4%	25.4%	0.5%	2.1%	5.1%	0.2%	8.0%
RCP 4.5	*Alternative 1*	2068	54.9%	0.2%	8.2%	0.9%	0.2%	0.8%	10.6%	4.4%	16.7%	0.6%	0.2%	1.2%	0.2%	1.1%
RCP 4.5	*Alternative 2*	2068	55.6%	0.5%	7.7%	2.9%	1.1%	4.5%	3.5%	0.5%	20.3%	0.9%	0.4%	1.2%	0.4%	1.1%
RCP 4.5	*Alternative 3*	2068	54.1%	0.2%	6.8%	3.0%	0.4%	1.5%	9.3%	4.9%	13.8%	1.0%	2.0%	0.3%	0.7%	1.8%
RCP 4.5	*Alternative 1*	2118	50.3%	0.9%	10.8%	2.0%	0.4%	2.5%	10.8%	2.0%	17.6%	0.7%	0.5%	0.7%	0.2%	1.0%
RCP 4.5	*Alternative 2*	2118	47.2%	2.1%	7.7%	3.5%	0.8%	3.6%	7.9%	1.2%	19.5%	1.1%	1.5%	1.4%	0.4%	2.3%
RCP 4.5	*Alternative 3*	2118	47.9%	0.5%	11.4%	4.1%	0.3%	3.1%	9.3%	4.8%	13.1%	1.1%	2.5%	0.2%	0.7%	1.4%
RCP 4.5	*Alternative 1*	2218	55.6%	0.5%	7.6%	2.8%	1.1%	4.4%	3.4%	0.5%	20.0%	0.9%	0.4%	1.2%	0.4%	1.1%
RCP 4.5	*Alternative 2*	2218	59.9%	0.2%	6.2%	3.1%	1.0%	3.7%	4.1%	0.4%	16.7%	0.9%	0.0%	1.7%	0.5%	1.5%
RCP 4.5	*Alternative 3*	2218	54.8%	0.4%	4.0%	5.1%	0.8%	6.7%	4.6%	0.3%	15.5%	1.3%	2.2%	1.6%	1.0%	1.8%
RCP 8.5	*Alternative 1*	2068	55.8%	0.1%	7.8%	1.3%	0.1%	0.6%	10.6%	4.6%	15.8%	0.8%	0.1%	1.2%	0.2%	1.2%
RCP 8.5	*Alternative 2*	2068	51.4%	0.8%	7.1%	3.0%	0.2%	2.3%	7.8%	1.8%	14.9%	1.3%	3.2%	1.1%	0.7%	3.6%
RCP 8.5	*Alternative 3*	2068	55.6%	0.6%	6.8%	1.8%	0.4%	1.5%	8.3%	5.8%	14.1%	0.9%	1.3%	0.6%	0.3%	2.8%
RCP 8.5	*Alternative 1*	2118	52.3%	0.9%	12.0%	1.1%	0.2%	1.1%	9.8%	3.7%	16.9%	0.8%	0.1%	0.4%	0.5%	0.3%
RCP 8.5	*Alternative 2*	2118	52.4%	2.0%	10.5%	2.4%	0.5%	3.5%	8.9%	0.9%	12.7%	1.3%	1.8%	0.5%	0.7%	2.1%
RCP 8.5	*Alternative 3*	2118	53.9%	1.1%	9.7%	2.7%	0.3%	3.3%	7.2%	5.7%	10.7%	2.0%	2.0%	0.1%	0.5%	1.3%
RCP 8.5	*Alternative 1*	2218	59.2%	0.3%	17.0%	0.4%	0.2%	2.7%	2.9%	0.0%	14.2%	2.0%	0.0%	0.1%	1.0%	0.0%
RCP 8.5	*Alternative 2*	2218	62.9%	0.9%	13.7%	1.7%	0.2%	4.6%	4.4%	0.0%	9.6%	1.2%	0.2%	0.0%	0.4%	0.1%
RCP 8.5	*Alternative 3*	2218	53.9%	1.6%	10.1%	2.3%	0.6%	11.0%	4.5%	0.0%	11.1%	2.5%	1.3%	0.0%	0.7%	0.1%

Table 22: Percent of MABI forest area dominated by each tree species or tree species group. All climate scenarios and management altneratives are shown. Current species composition is shown in yellow within the top row of the table.

In the next fifty years, sugar maple is projected to increase under a changing climate and under all management alternatives (Table 22). Under current climate conditions, sugar maple dominance remains relatively stable (Figure 12). Under a low emissions climate future (RCP 4.5), sugar maple is projected to increase in percent dominance under all alternative management regimes (Figure 14). It is projected that by the end of the two-hundred-year simulation, sugar maple will likely increase in dominance under both RCP 4.5 (Figure 13) and the high emissions scenario (RCP 8.5) (Figure 15) emission climate scenarios.

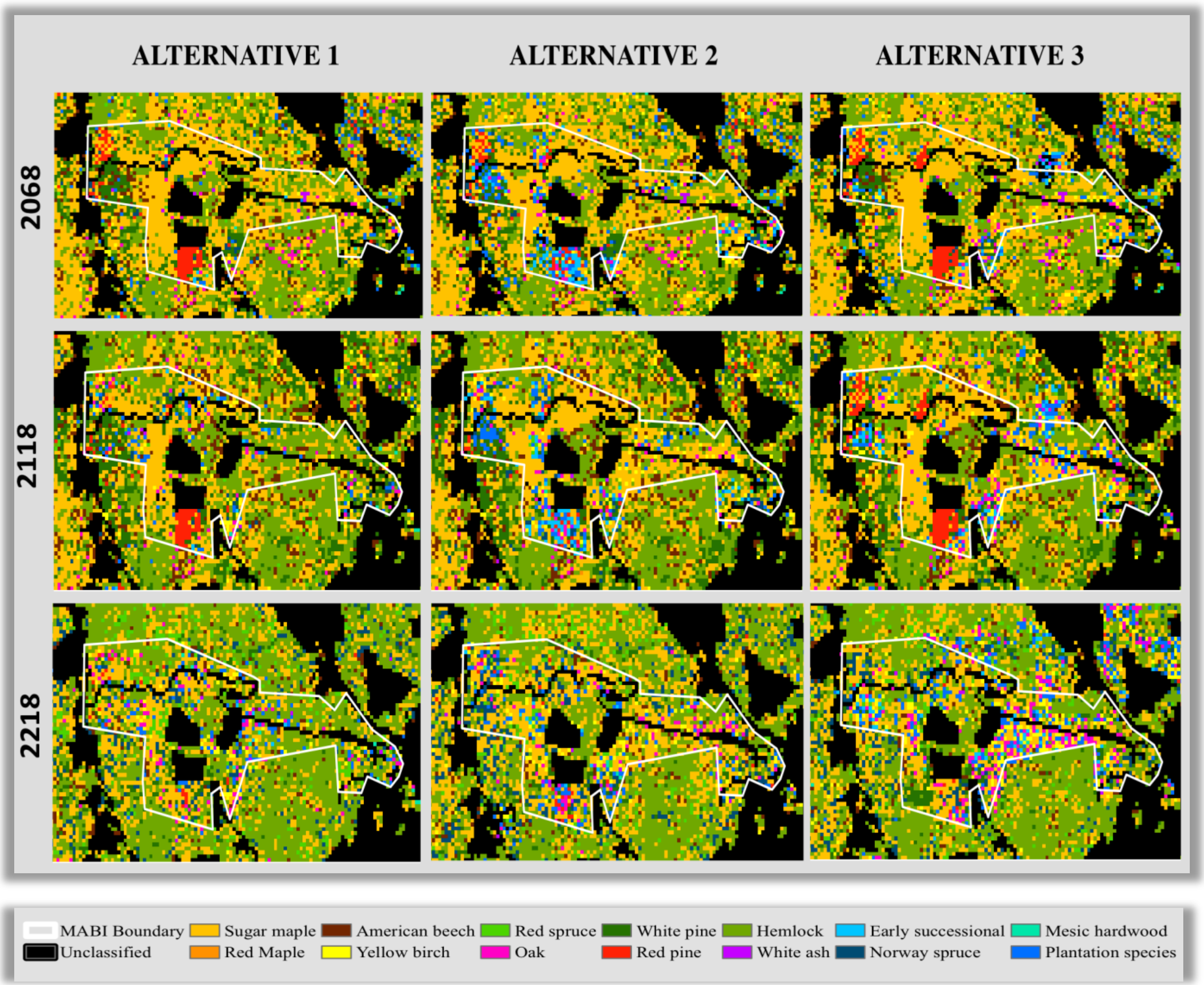


Figure 11: Projected future forest composition under three alternative management scenarios and under a continuation of current climate conditions. Projections of tree species dominance within MABI is shown for future years 2068, 2118, and 2218

Eastern hemlock is projected to maintain current levels of dominance under a continuation of current climate condition and is projected to increase under Alternative 1 management especially (Figure 11 & 12). However, eastern hemlock declines in percent dominance under both RCP 4.5 and RCP 8.5 climate change scenarios (Figure 14 &16). Projected hemlock decline is greatest under RCP 8.5 by year 2218 (Table 21, Figure 11). The expected impacts of hemlock woolly adelgid were not simulated in this modeling effort which would likely result in steeper declines in hemlock dominance.

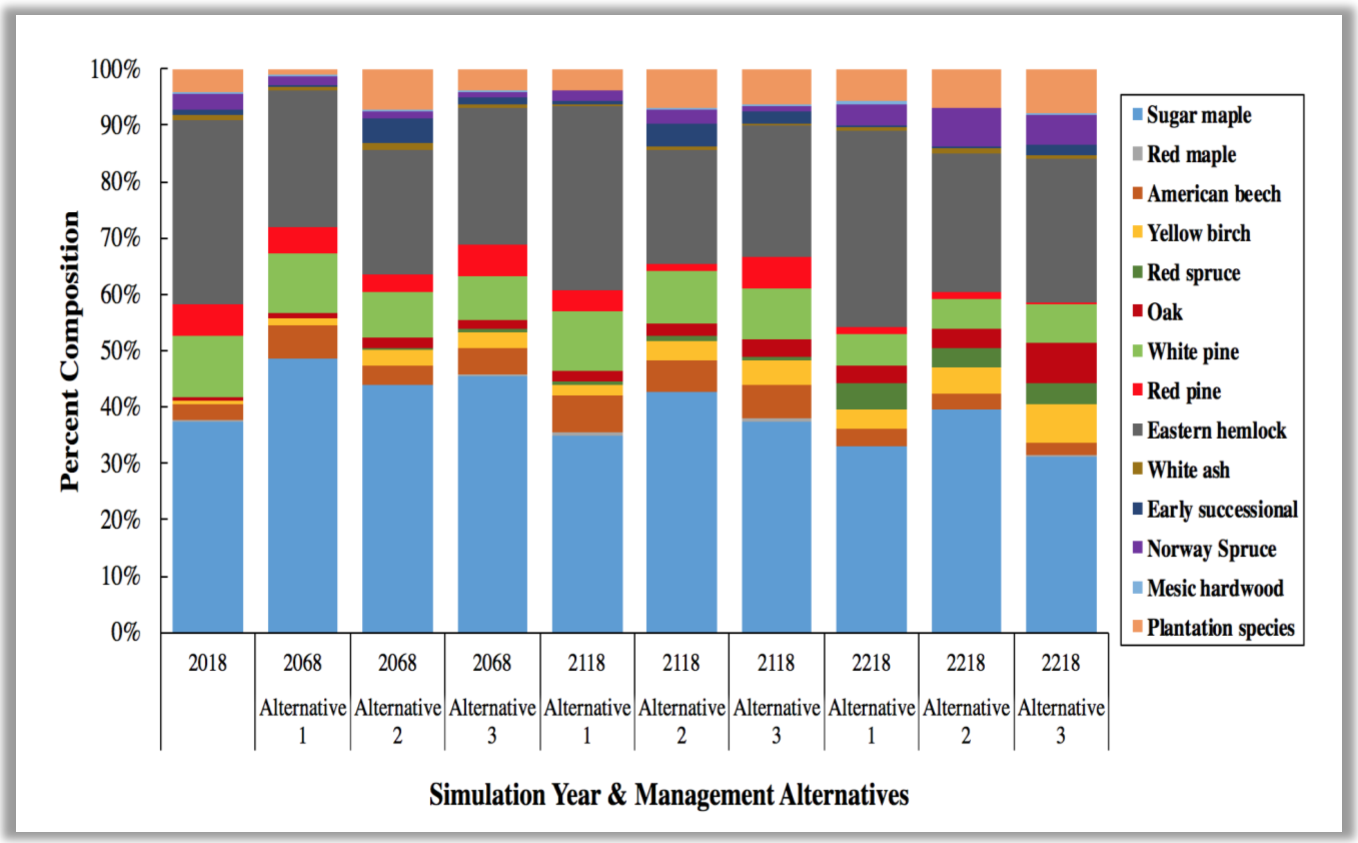


Figure 12: Percentage of forested landscape dominated by 14 species and species groups under three alternative management regimes and under a continuation of current climate conditions. Current percentages for each species at year 2018 is shown on the far left of the figure.

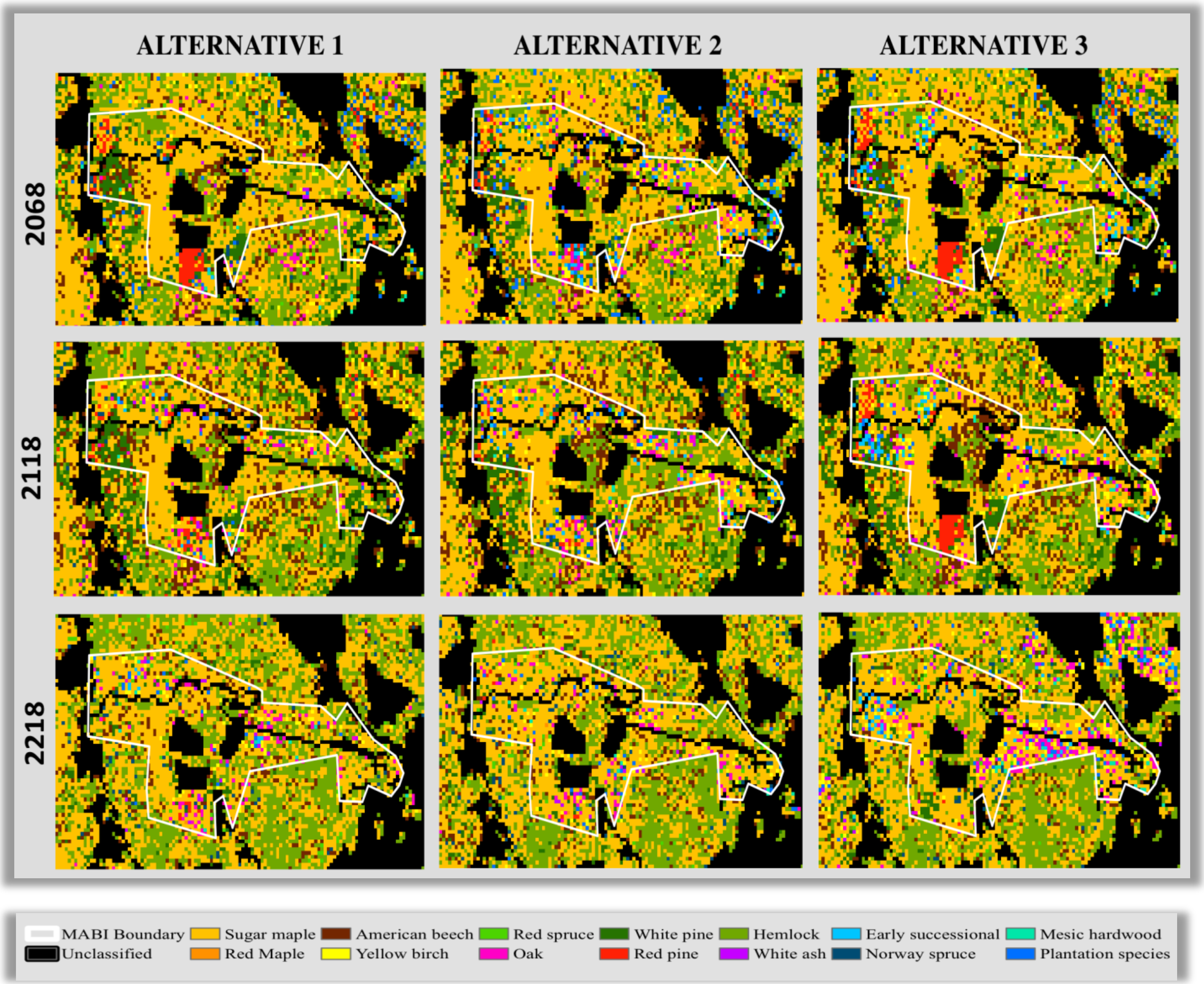


Figure 13: Projected future forest composition under three alternative management scenarios and under the modest climate warming scenario (RCP4.5). Projections of tree species dominance within MABI is shown for future years 2068, 2118, and 2218.

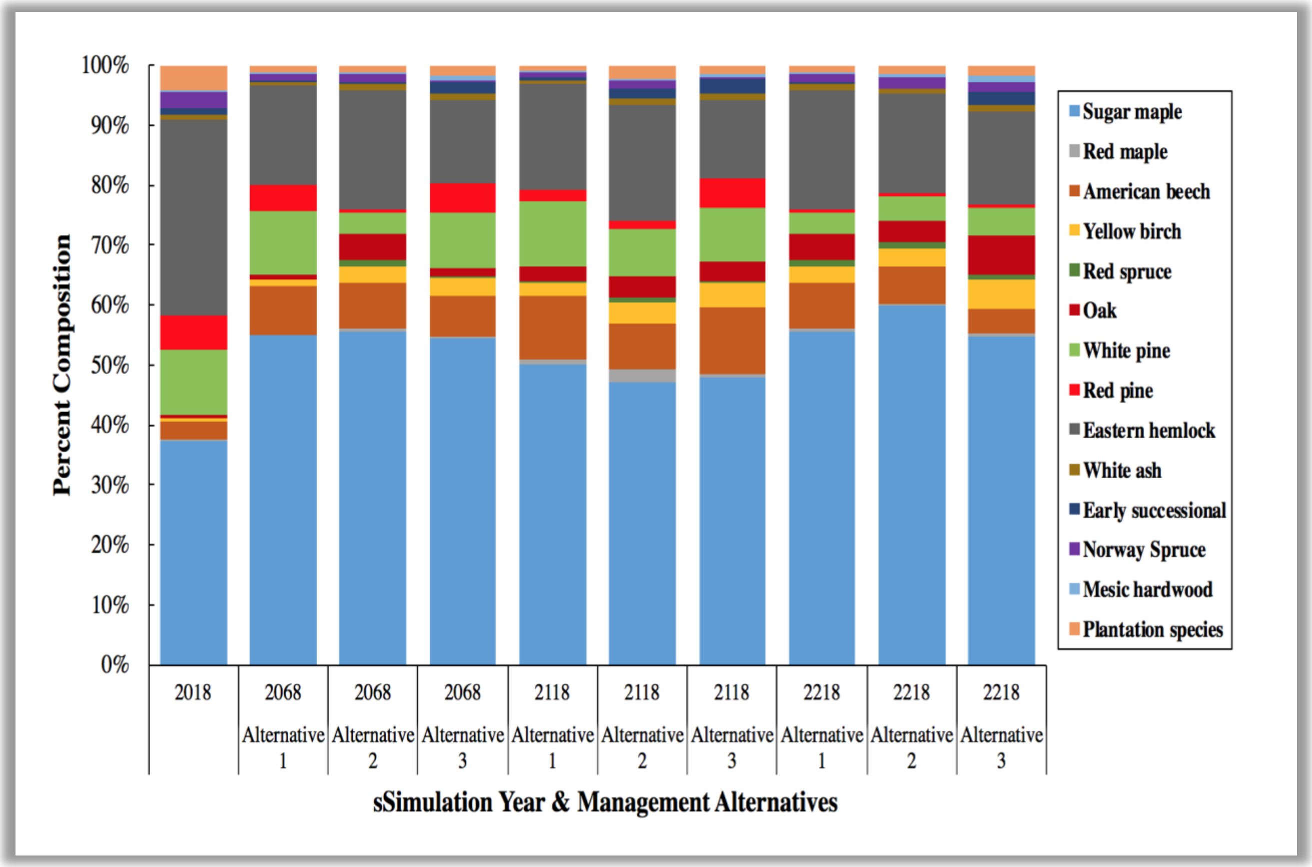


Figure 14: Percentage of forested landscape dominated by 14 species and species groups under three alternative management regimes and under RCP 4.5 climate projections. Current percentages for each species at year 2018 is shown on the far left of the figure.

Red spruce and yellow birch both increase the most in percent dominance under current climate conditions when compared to RCP 4.5 and RCP 8.5 climate scenarios (Figure 12, 14, & 16). Alternative 2 and 3 both promoted the greatest increases in yellow birch dominance across all climate scenarios (Table 22). Red maple and red oak both increase in percent dominance under RCP 4.5 (Figure 13). While Alternative 3 is likely to promote the greatest increase in red oak dominance over the next two hundred years, Alternative 2 is likely to also be effective in promoting increased oak dominance. Projected increases in red oak dominance was greatest under RCP 8.5 when compared to all other climate scenarios and regardless of management alternatives (Table 22).

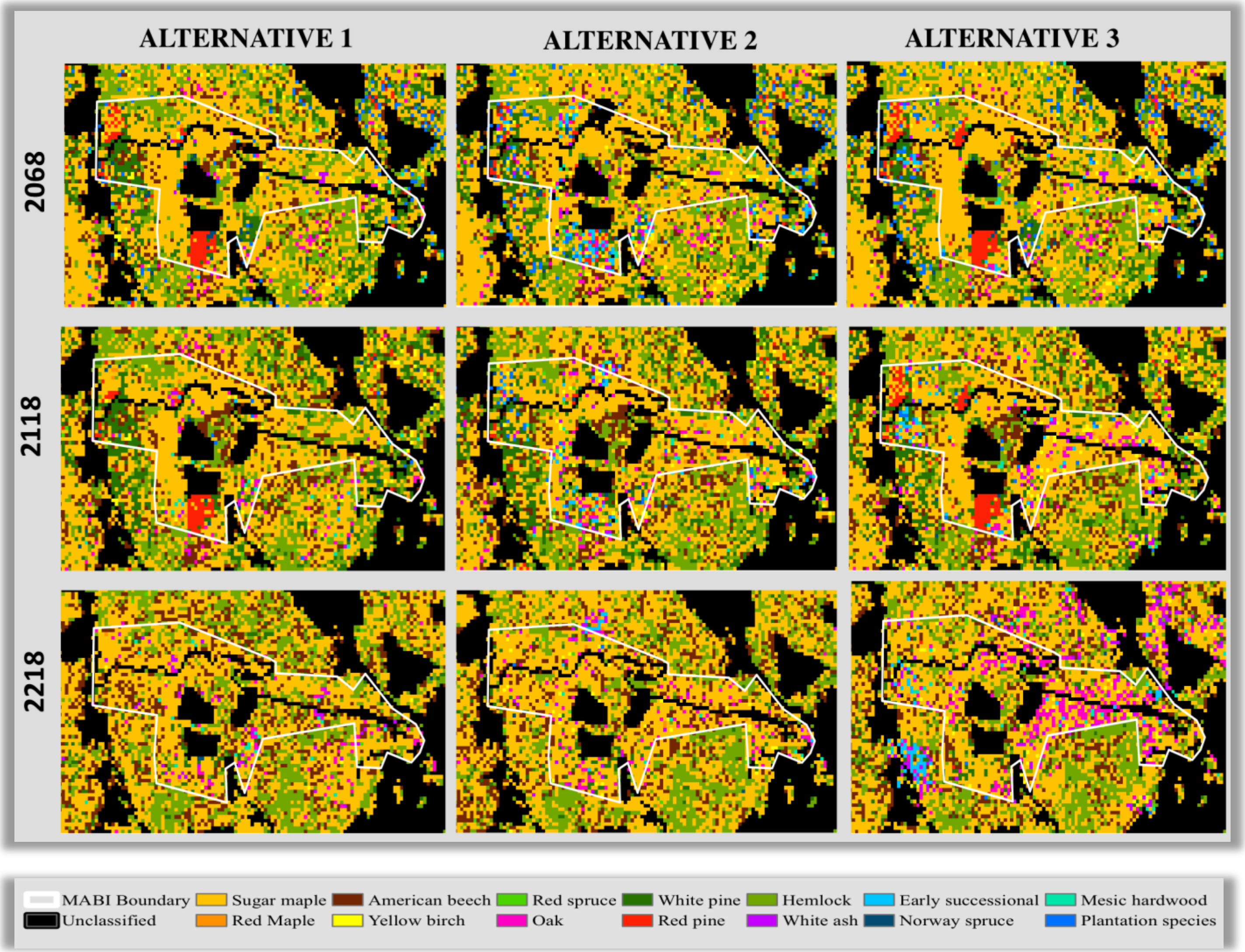


Figure 15: Projected future forest composition under three alternative management scenarios and under the modest climate warming scenario (RCP8.5). Projections of tree species dominance within MABI is shown for future years 2068, 2118, and 2218.

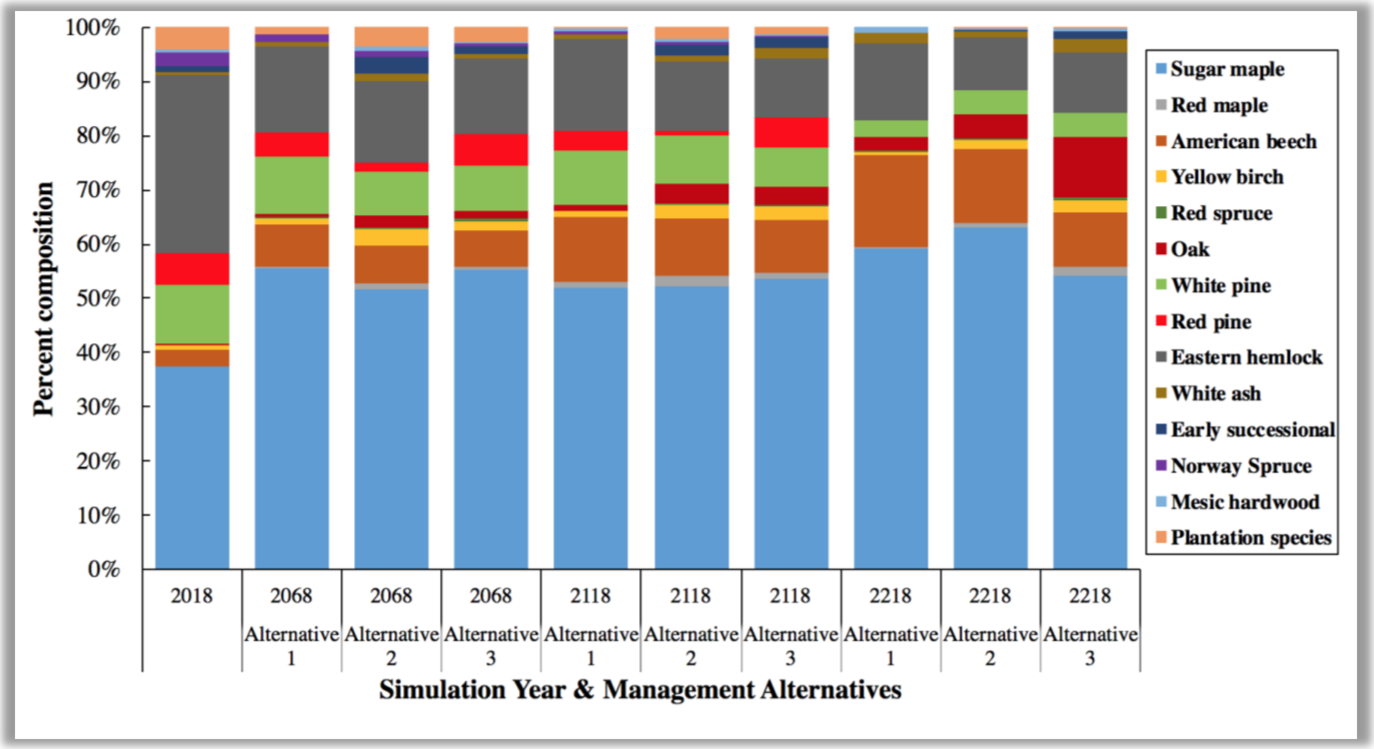


Figure 16: Percentage of forested landscape dominated by 14 species and species groups under three alternative management regimes and under RCP 8.5 climate projections. Current percentages for each species at year 2018 is shown on the far left of the figure.

American beech is projected to increase with a warming climate (Table 22). Increases in beech dominance will likely be greatest under higher emissions climate futures (Table 22). Under RCP 8.5, Alternative 2 was most effective in reducing American beech percent dominance over the next one-hundred years while Alternative 3 was most effective in controlling beech dominance at the end of the two-hundred-year simulation (Figure 16).

Evaluation of findings

Climate change is likely to play a role in shifting species composition at MABI. Eastern hemlock is likely to decline under a warming climate and this is not taking into account the major threat of hemlock woolly adelgid which was not represented in this modeling effort. Sugar maple is a dominant species currently and is likely to continue to dominate many sites throughout MABI. American beech is likely to increase in percent dominance as the climate warms as is red maple and red oak. Red spruce currently comprises a very small proportion of the forest composition but is projected to experience an increase in percent dominance under current climate condition. However, red spruce is not projected to experience the same increase in percent dominance under the two climate change scenarios. This may indicate that red spruce is well adapted to the climate we have been experiencing for the past thirty years, but may be more vulnerable as the climate changes.

Alternative management does appear to influence future forest composition at MABI. Alternative 1 tended to promote shade tolerant species, as would be expected for a management approach heavily reliant on single tree selection. Sugar maple, eastern hemlock, and American beech were species which tended to fair well under this approach.

Alternative 2 also sustained the dominance of shade tolerant species such as sugar maple and American beech but promoted a greater representation of mid-tolerant and even intolerant species. Yellow birch, red maple, and red oak all experienced increased percent dominance under this alternative management approach. Alternative 2 also resulted in a greater increase in early successional species. This approach tended to increase the diversity of species represented within the forest.

Alternative 3 sustained sugar maple dominance over the two-hundred-year simulation period and limited American beech dominance when compared to the other alternatives. Additionally, this alternative resulted in the highest proportion of yellow birch, red maple, and red oak at the end of the simulation. This approach was most effective in transitioning forest composition towards a greater representation of future adapted tree species.

Key Findings

- **Climate change will likely impact future forest composition at MABI**
  - Eastern hemlock, red spruce, are expected to be vulnerable to a changing climate.
  - American beech will likely increase in percent dominance under low and high emissions climate futures.
  - Sugar maple is projected to sustain current levels and potentially increase in percent dominance.
  - Red oak and red maple are likely to increase in percent dominance under climate change.
- **Management alternatives are projected to sustain a diverse mix of desirable tree species and increase representation of future adapted species.**
  - **Alternative 1** is likely to promote the continued growth and dominance of shade tolerant species such as sugar maple and American beech.
  - **Alternative 2** is likely to sustain species diversity over time under climate change. Yellow birch and red oak increase in percent dominance under this alternative as do early successional species.
  - **Alternative 3** is likely to promote the establishment and increased dominance of northern red oak, yellow birch, and red maple. Results in the largest increase in red oak dominance. Projected to limit American beech dominance over the next two centuries under a high emissions scenario (RCP 8.5).

Conclusion

Climate change and a range of stressors are likely impact forest in our region and at MABI. These changes will likely lead to increasing challenges for resource managers tasked with ensuring the delivery of critical goods and services to diverse stakeholders. We know that climate change is currently impacting forest systems in our region and these impacts are only projected to become more evident and impactful.

This report presents a framework for managing forest systems in the context of a changing climate. The iterative process presented here can be applied to any management scenario and reapplied as conditions change or as outcomes diverge from what is expected or desired. The foundation of this framework is the concept of vulnerability. By viewing the forest through the lens of vulnerability, we can begin to understand the stressors which pose a risk to the forest system we are managing and begin to understand the potential ability of that forest system to resist or be resilient to stressors (adaptive capacity).

The concept of vulnerability is not new to resource managers who have traditionally used their own expert knowledge and experience to understand the condition of a forest resource and its potential to reach a desired future condition. However, with the pace at which the climate is changing and with the increased prevalence of new stressors such as invasive insects and diseases, managers are looking for additional tools to understand vulnerability in this new context and effectively implement adaptive management. This report synthesizes some of approaches managers are taking to address these challenges and outlines a process for mangers looking to implement and evaluate adaptive management.

This report expands upon the adaptive management framework and uses computer modeling techniques to project future forest conditions under a range of management alternatives and climate scenarios. Results from these simulations suggest that climate change will influence species composition over time. These modeling efforts also suggest that management can assist in maintaining desirable species and even increase species diversity, thereby promoting greater forest resilience in the face of a changing climate. We also see that transitional efforts such as small scale planting and the creation of larger canopy openings may indeed increase the representation of tree species well adapted to future climatic conditions over time.

The integration of these techniques into the adaptive management applied at MABI will serve to further strengthen the critical role of the Park in serving as an example of historic and emerging sustainable forest stewardship approaches for the region.

Additional Resources

I: MABI Forest Inventory Analysis (2012 & 2017)

To describe the current condition and adaptive capacity of each forest system, we assessed both overstory and understory forest conditions. Overstory conditions are compared between 2012 and 2017 using a distribution of number of tree per acre by tree diameters (inches) and species. Tree diameters are binned into 2-inches classes. Species composition, diversity, and adaptability are represented for each measurement year for two size classes of trees, overstory and midstory sized trees. Overstory trees, also referred to as Sawtimber sized trees, are larger than 9-inches in diameter at breast height (DBH) for softwoods and 11-inches DBH for hardwoods. Midstory trees, commonly referred to as Poletimber, are trees larger then 4-inches DBH and less than 9-inches for softwoods and 11-inches DBH for hardwoods. Adaptive capacity was determined using the weighted average of species adaptability scores based on the density and abundance of each species (measured by the *importance value)* within the forest system.

Understory conditions are described by assessing both saplings and seedlings. Saplings are young trees greater than 1-inch DBH and less than 4-inches DBH. Seedlings are trees that are less than 1-inch in diameter. Adaptive capacity was determined for the understory in each forest using the weighted average of species specific adaptability scores. Adaptability scores for each species were corrected based on how abundant each species was within the forest system relative to a desired stocking level. For saplings, it is desirable to have at least 350 saplings per acre. For seedlings, 1,000 individuals per acre is considered a desirable stocking level. To assess the forest systems current carbon storage and mitigation potential, we calculated the total above ground biomass within each forest system.

We analyzed forest inventory data collected at MABI from 2012 and 2017 to assess the current condition and adaptive capacity of each forest system. Species composition, diversity, adaptive capacity, and mitigation potential were determined and used for our evaluation. To assess adaptive capacity, we utilized relative *adaptability scores* for each individual tree species developed by the US Forest Service/Northeast Research Station's *Tree Atlas* initiative (Iverson et al. 2008). This approach has also been used in the recently published *Vulnerability Assessment and Synthesis for New England and New York* (Janowiak et al. 2018).

Adaptability scores are a metric used to describe an individual tree species' ability to adapt and respond to environmental change. Individual tree species traits (shade tolerance, drought tolerance, regeneration ability, etc.) and characteristics related to how trees respond to disturbance (tolerance to insects and disease, browse, fire, harvests, etc.) are both taken into account (Kabrick et al. 2017). Scores range from 0-8.5 and stands with weighted average scores less than 3.3 indicate lower adaptability (**L**), scores between 3.3 and 5.2 indicate moderate adaptability (**M**), and scores greater than 5.2 indicate higher adaptability potential (**H**) for that forest system (Kabrick et al, 2017).

Northern Hardwood Forest Adaptive Capacity

Northern hardwood forest system summary table							
2012	**Size Class**	**Basal Area (ft^2/acre)**	**Trees Per Acre**	**Species Richness**	**Species Diversity**	**Species Evenness**	**Adaptability Score**
	Overstory	**77**	**51**	14	1.91	0.72	4.28
	Midstory	**32**	**103**	11	1.84	0.77	4.38
	Saplings	0	252	13	0.81	0.67	1.51
	Seedlings		3948	25	1.11	0.71	2.41
	TOTAL/ AVERAGE	**109**	**154**	**16**	**1.42**	**0.72**	**3.15**
2017	Overstory	**73**	**50**	12	1.74	0.7	4.23
	Midstory	**28**	**88**	11	1.63	0.68	4.6
	Saplings	0	248	13	0.82	0.64	1.36
	Seedlings		4114	25	1.09	0.62	2.21
	TOTAL/ AVERAGE	**101**	**138**	**15**	**1.32**	**0.66**	**3.10**

Table 9: Northern Hardwood forest system summary table.

Northern Hardwood Diameter Distribution 2012 & 2017

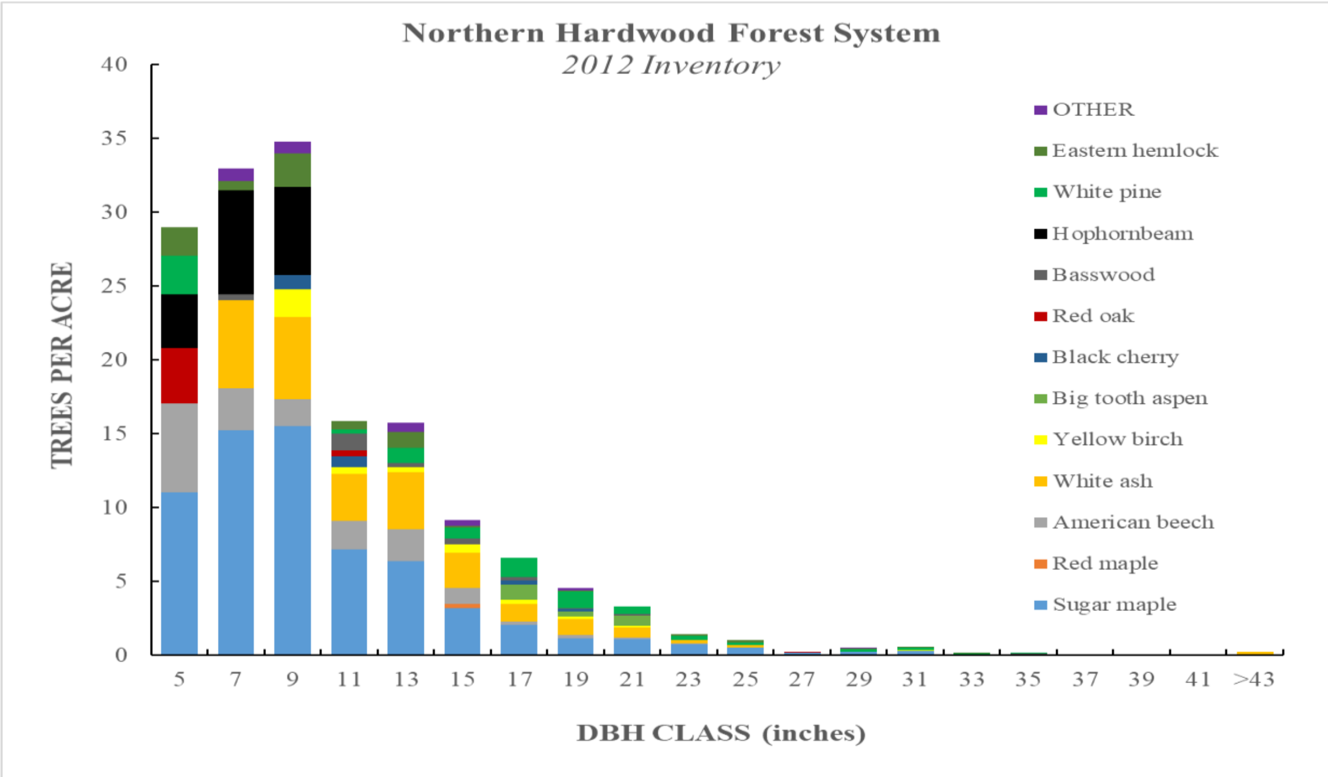


Figure 17: 2012 Northern Hardwood DBH distribution

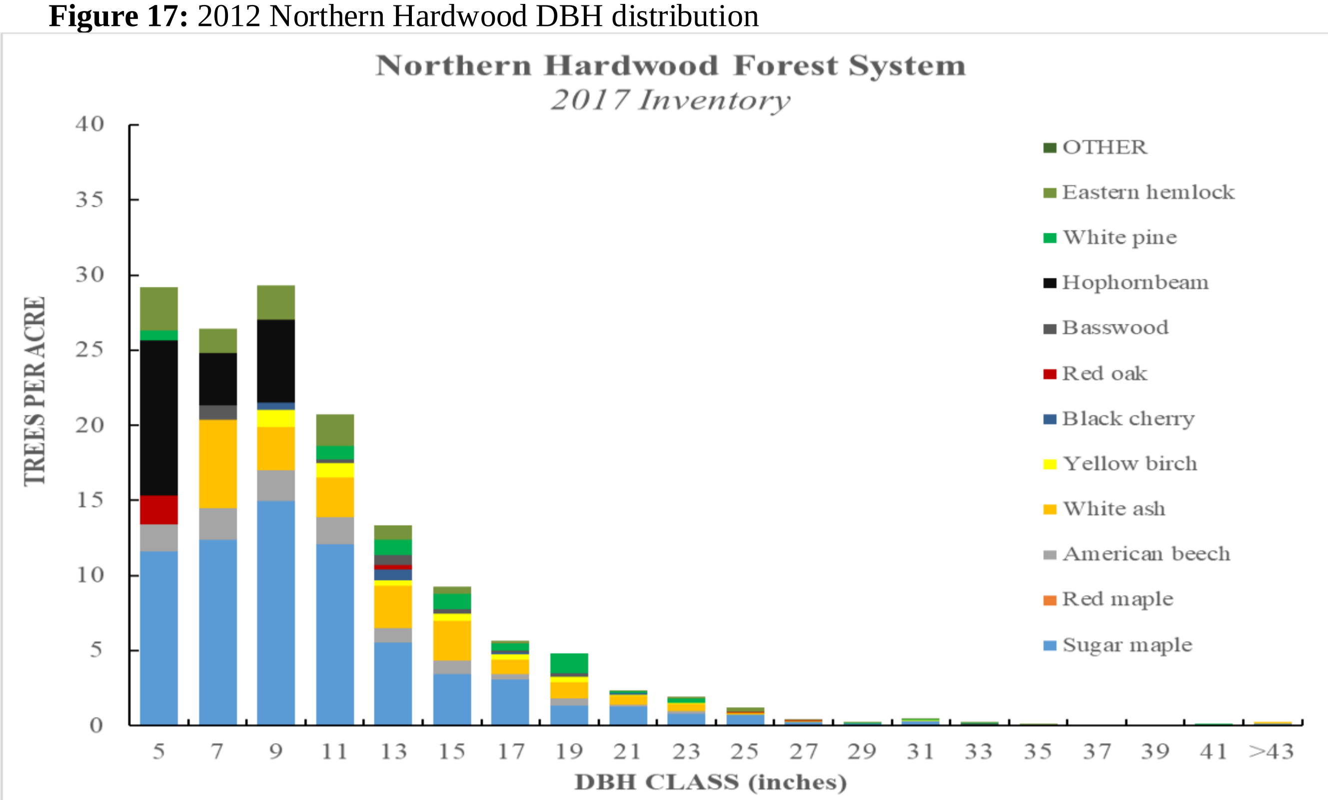


Figure 18: 2017 Northern Hardwood DBH distribution

Northern Hardwood Forest System Overstory Analysis 2012-2017

Overstory Composition

2012

Species	Basal Area (ft^2/acre)	Trees Per Acre	Importance Value
Sugar maple	28.97	19	38%
White ash	15.04	11	21%
Eastern white pine	11.11	6	13%
American beech	5.01	4	8%
Eastern hemlock	3.94	2	5%
Bigtooth aspen	3.89	2	5%
Yellow birch	2.45	2	3%
Red maple	0.37	<1	1%
Northern red oak	0.55	<1	1%
Other	5.67	4	6%
TOTAL	**77**	**51**	**100%**

2017

Species	Basal Area (ft^2/acre)	Trees Per Acre	Importance Value
Sugar maple	30.54	21	42%
White ash	16.10	12	23%
Eastern white pine	8.15	4	10%
Eastern hemlock	5.56	4	8%
American beech	4.17	3	6%
Yellow birch	2.58	2	3%
American basswood	1.98	1	3%
Black cherry	1.48	1	2%
Other	2.44	2	3%
TOTAL	**73**	**50**	**100%**

Table 2: Northern Hardwood overstory composition 2012 & 2017

Overstory Diversity and Adaptability 2012 & 2017

Year	Species Richness	Species Diversity	Species Evenness	Trees/acre	Adaptability Score
2012	14	1.91	0.72	51	4.28(M)
2017	12	1.74	0.70	50	4.23(M)

Table 3: Northern Hardwood overstory diversity and adaptability 2012 & 2017

Midstory Composition 2012			
Species	**Basal Area (ft^2/acre)**	**Trees Per Acre**	**Importance Value**
Sugar maple	15.31	46	44%
Hophornbeam	5.00	17	16%
White ash	4.23	13	13%
American beech	3.14	12	12%
Northern red oak	0.56	4	4%
Eastern hemlock	0.88	4	4%
White pine	0.37	3	3%
Yellow birch	0.96	2	2%
Other	1.55	2	2%
TOTAL	**32**	**103**	**100%**
2017			
Species	**Basal Area (ft^2/acre)**	**Trees Per Acre**	**Importance Value**
Sugar maple	13.85	42	49%
White ash	4.27	12	15%
Hophornbeam	3.61	14	14%
American beech	2.39	7	8%
Eastern hemlock	1.17	4	5%
Northern red oak	0.56	3	3%
Paper birch	0.56	1	2%
Other	2.76	5	4%
TOTAL	**28**	**88**	**100%**

Table 4: Northern Hardwood midstory composition 2012 & 2017

Midstory Diversity and Adaptability 2012 & 2017					
Year	**Species Richness**	**Species Diversity**	**Species Evenness**	**Trees/acre**	**Adaptability Score**
2012	11	1.84	0.77	103	4.38(M)
2017	11	1.63	0.68	88	4.60(M)

Table 5: Northern Hardwood midstory diversity and adaptability 2012 & 2017

Sapling Composition 2012 & 2017		
Species	**% Composition 2012**	**% Composition 2017**
American beech	36.3%	50.3%
Sugar maple	45.2%	22.6%
Hophornbeam	8.5%	13.0%
White ash	4.2%	3.4%
American basswood	0.6%	3.8%
Eastern white pine	0.8%	2.2%
Striped maple	2.0%	2.3%
Eastern hemlock	1.1%	0.9%
Other	1.3%	1.5%
TOTAL	**100.0%**	**100.0%**

Table 6: Northern Hardwood sapling composition 2012 & 2017

Sapling Diversity and Adaptability 2012 & 2017					
Year	**Species Richness**	**Species Diversity**	**Species Evenness**	**Saplings/acre**	**Adaptability Score**
2012	13	0.81	0.67	252	1.51(L)
2017	13	0.82	0.64	248	1.36(L)

Table 7: Northern Hardwood sapling diversity and adaptability 2012 & 2017

Seedling Composition 2012 & 2017		
Species	**% Composition 2012**	**% Composition 2017**
White ash	26.9%	27.4%
Sugar maple	21.3%	24.9%
Hophornbeam	13.2%	18.3%
American beech	14.9%	16.8%
Northern red oak	1.6%	2.3%

Eastern white pine	1.2%	2.3%
Black cherry	2.4%	1.2%
Yellow birch	0.7%	1.2%
Red maple	3.0%	1.2%
Eastern hemlock	0.9%	1.0%
Other	13.9%	4.6%
TOTAL	**100.0%**	**100.0%**

Table 8: Northern Hardwood seedling composition 2012 & 2017

Seedling Diversity and Adaptability 2012 & 2017					
Year	**Species Richness**	**Species Diversity**	**Species Evenness**	**Seedlings/acre**	**Adaptability Score**
2012	25	1.11	0.71	3948	2.41(L)
2017	20	1.09	0.62	4114	2.21(L)

Table 9: Northern Hardwood seedling diversity and adaptability 2012 & 2017

Mitigation Potential

Mitigation Potential - Biomass storage 2012 & 2017				
Year	**Living Biomass (tons/acre)**	**Standing Dead Biomass (tons/acre)**	**Downed Woody Debris (tons/acre)**	**Total Biomass (tons/acre)**
2012	51.5	3.8	9.4	64.6
2017	52.7	6.4	9.8	69.0

Table 10: Northern Hardwood Mitigation Potential – Biomass Storage table

Plantation Forest System Adaptability

PLANTATION FOREST SYSTEM SUMMARY TABLE							
2012	***Size Class***	***Basal Area (ft^2/acre)***	***Trees Per Acre***	***Species Richness***	***Species Diversity***	***Species Evenness***	***Adaptability Score***
	Overstory	145	**77**	13	1.99	0.80	3.72
	Midstory	13	**54**	11	1.84	0.77	4.38
	Saplings	-	182	16	0.96	0.59	0.79
	Seedlings	-	5129	22	1.20	0.68	3.23
	TOTAL/ AVERAGE	**158**	**131**	**16**	**1.50**	**0.71**	**3.03(L-M)**
2017	Overstory	127	**69**	14	1.96	0.74	3.68
	Midstory	15	**66**	10	1.72	0.75	4.64
	Saplings	-	250	20	1.09	0.72	1.22
	Seedlings	-	5493	23	1.35	0.74	3.10
	TOTAL/ AVERAGE	**142**	**135**	**17**	**1.53**	**0.74**	**3.16(L-M)**

Table 11: Plantation forest system summary table 2012 & 2017

Plantation DBH Distribution 2012 & 2017

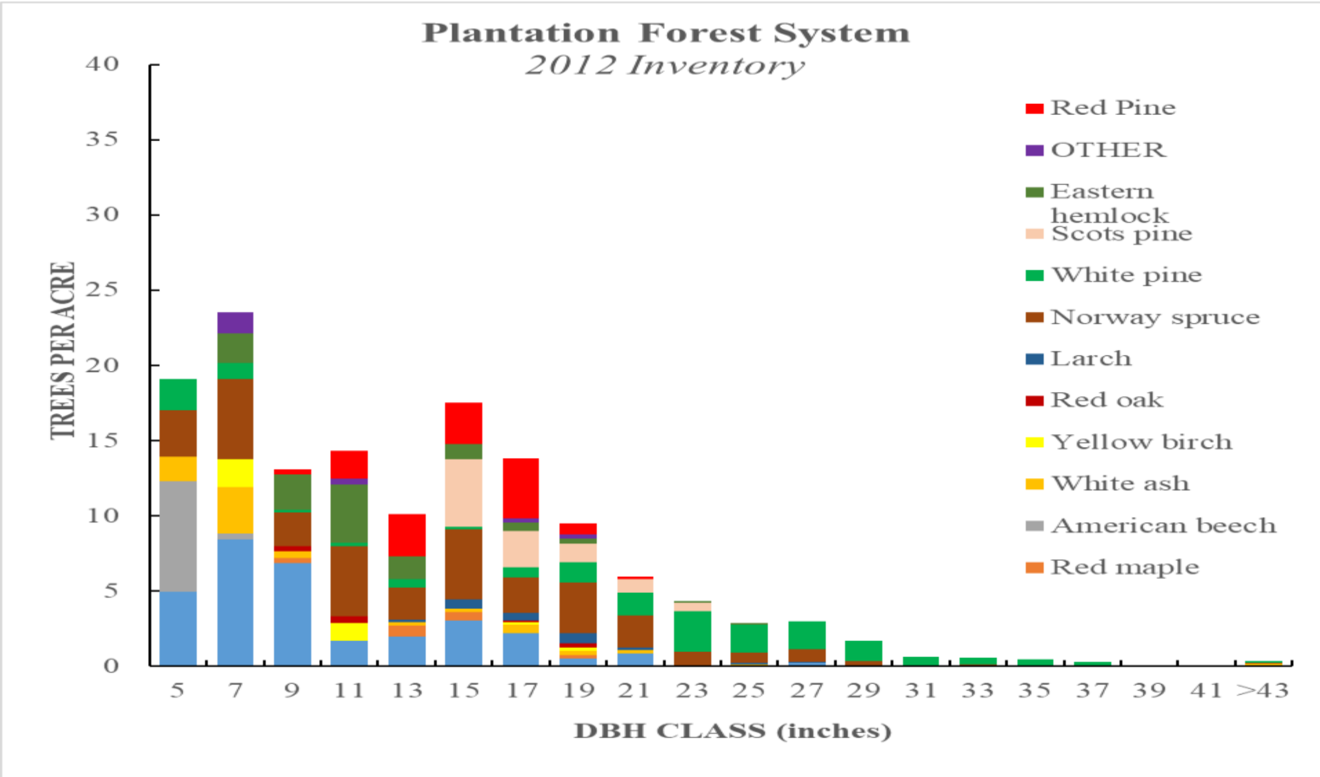


Figure 5: Plantation forest system 2012 DBH distribution

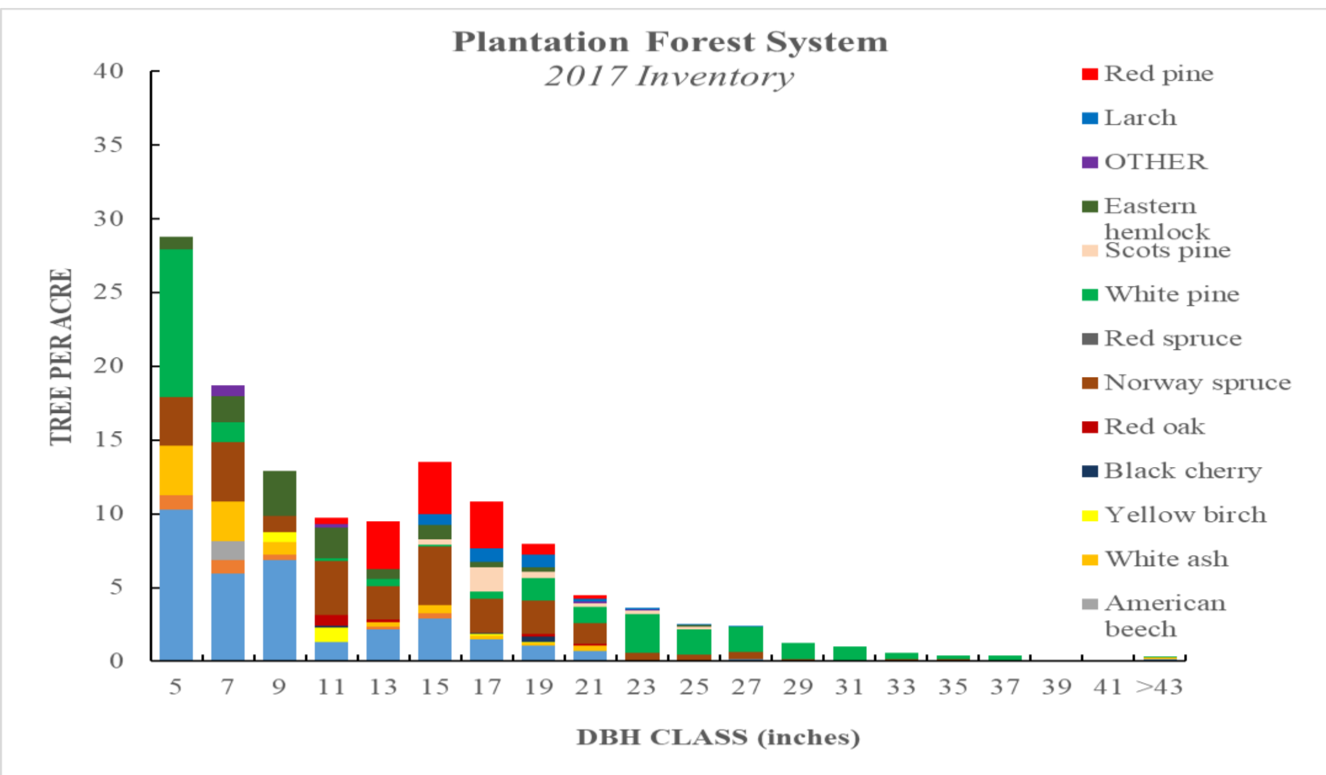


Figure 6: Plantation forest system 2017 DBH distribution

Overstory Analysis 2012-2017

Overstory Composition 2012			
Species	**Basal Area (ft^2/acre)**	**Trees Per Acre**	**Importance Value**
White pine	46.71	14	25%
Norway spruce	33.27	18	22%
Red pine	15.15	11	13%
Scots pine	15.76	10	12%
Sugar maple	14.94	10	12%
Eastern hemlock	6.97	5	6%
European larch	4.09	2	3%
White ash	2.98	2	2%
Red maple	1.67	1	2%
Yellow birch	1.06	1	1%
Other	2.4	3	2%
TOTAL	**145**	**77**	**100%**
2017			
Species	**Basal Area (ft^2/acre)**	**Trees Per Acre**	**Importance Value**
Eastern white pine	46.83	13	27%
Norway spruce	32.09	21	27%
Sugar maple	14.71	10	12%
Red pine	11.73	9	11%
Eastern hemlock	6.52	7	7%
Scots pine	8.18	5	6%
European larch	4.24	2	3%
White ash	2.77	2	2%
Other	3.93	3	5%
TOTAL	**131**	**72**	**100**

Table 12: Plantation forest system overstory composition 2012 & 2017

Overstory Diversity and Adaptability 2012 & 2017					
Year	**Species Richness**	**Species Diversity**	**Species Evenness**	**Trees/acre**	**Adaptability Score**
2012	13	1.99	0.80	77	3.72(M)
2017	14	1.96	0.74	72	3.68(M)

Table 13: Plantation overstory diversity and adaptability

Midstory Composition 2012			
Species	**Basal Area (ft^2/acre)**	**Trees Per Acre**	**Importance Value**
Sugar maple	6.08	21	42%
Norway spruce	1.97	9	16%
American beech	1.00	8	11%
White ash	1.06	5	9%
Eastern hemlock	0.98	3	6%
White pine	0.50	3	5%
Yellow birch	0.76	2	5%
Other	0.65	3	6%
TOTAL	**13**	**54**	**100%**
2017			
Species	**Basal Area (ft^2/acre)**	**Trees Per Acre**	**Importance Value**
Sugar maple	7.59	31	48%
Eastern white pine	1.21	11	13%
Norway spruce	1.61	7	10%
White ash	1.15	6	8%
Eastern hemlock	1.21	4	7%
Yellow birch	0.76	2	4%
Red maple	0.55	3	4%
Other	0.92	2	6%
TOTAL	**15**	**66**	**100%**

Table 14: Plantation forest system midstory composition 2012 & 2017

Midstory Diversity and Adaptability 2012 & 2017					
Year	**Species Richness**	**Species Diversity**	**Species Evenness**	**Trees/acre**	**Adaptability Score**
2012	11	1.84	0.77	54	4.38(M)
2017	10	1.72	0.75	66	4.64(M)

Table 15: Plantation forest system midstory diversity and adaptability 2012 & 2017

REGENERATION ANALYSIS 2012 & 2017

Sapling Composition 2012 & 2017		
Species	**% Composition 2012**	**% Composition 2017**
Sugar maple	18.0%	28.2%
American beech	22.8%	22.6%
Hophornbeam	17.5%	12.5%
Striped maple	4.1%	8.3%
White ash	10.5%	8.0%
Eastern hemlock	7.0%	4.6%
Red maple	5.5%	3.6%
Other	14.6%	12.2%
TOTAL	**100.0%**	**100.0%**

Table 16: Plantation forest system sapling composition 2012 & 2017

Sapling Diversity and Adaptability 2012 & 2017					
Year	**Species Richness**	**Species Diversity**	**Species Evenness**	**Saplings/acre**	**Adaptability Score**
2012	16	0.96	0.59	182	0.79(L)
2017	20	1.09	0.72	250	1.22(L)

Table 17: Plantation forest system sapling diversity and adaptability 2012 & 2017

Seedling Composition 2012 & 2017		
Species	**% Composition 2012**	**% Composition 2017**
Sugar maple	20.2%	29.4%
White ash	32.3%	27.5%
Hophornbeam	12.3%	10.2%
Mountain maple	3.0%	7.4%
American beech	9.6%	6.9%
Striped maple	5.6%	5.7%
Northern red oak	2.4%	3.2%
Other	14.6%	9.7%
TOTAL	**100.0%**	**100.0%**

Table 18: Plantation forest system seedling composition 2012 & 2017

Seedling Diversity and Adaptability 2012 & 2017					
Year	**Species Richness**	**Species Diversity**	**Species Evenness**	**Seedlings/acre**	**Adaptability Score**
2012	22	1.20	0.68	5129	3.23(L-M)
2017	23	1.35	0.74	5493	3.10(L-M)

Table 19: Plantation forest system seedling diversity and adaptability 2012 & 2017

Mitigation Potential

Mitigation Potential - Biomass storage 2012 & 2017				
Year	**Living Biomass (tons/acre)**	**Standing Dead Biomass (tons/acre)**	**Downed Woody Debris (tons/acre)**	**Total Biomass (tons/acre)**
2012	73.5	3.7	8.0	85.3
2017	72.9	9.1	13.3	95.4

Table 20: Plantation forest system mitigation potential 2012 & 2017

Hemlock-Hardwood Forest System Adaptability

HEMLOCK-HARDWOOD FOREST SYSTEM SUMMARY TABLE							
2012	***Size Class***	***Basal Area (ft^2/acre)***	***Trees Per Acre***	***Species Richness***	***Species Diversity***	***Species Evenness***	***Adaptability Score***
	Overstory	147	**89**	13	1.24	0.48	3.25
	Midstory	18	**78**	12	2.05	0.83	3.82
	Saplings	-	97	10	0.85	0.59	0.39
	Seedlings	-	6271	11	0.75	0.41	2.11
	TOTAL/ AVERAGE	**165**	**167**	**12**	**1.22**	**0.58**	**2.39(L)**

2017	Overstory	166	**119**	12	1.2	0.48	3.21
	Midstory	22	**100**	10	1.71	0.74	4.13
	Saplings	-	95	10	0.75	0.56	0.44
	Seedlings	-	2401	12	0.98	0.61	2.13
	TOTAL/ AVERAGE	**188**	**219**	**11**	**1.16**	**0.60**	**2.48(L)**

Table 21: Hemlock – Hardwood Forest system summary table 2012 & 2017

Hemlock-Hardwood DBH Distribution 2012 & 2017

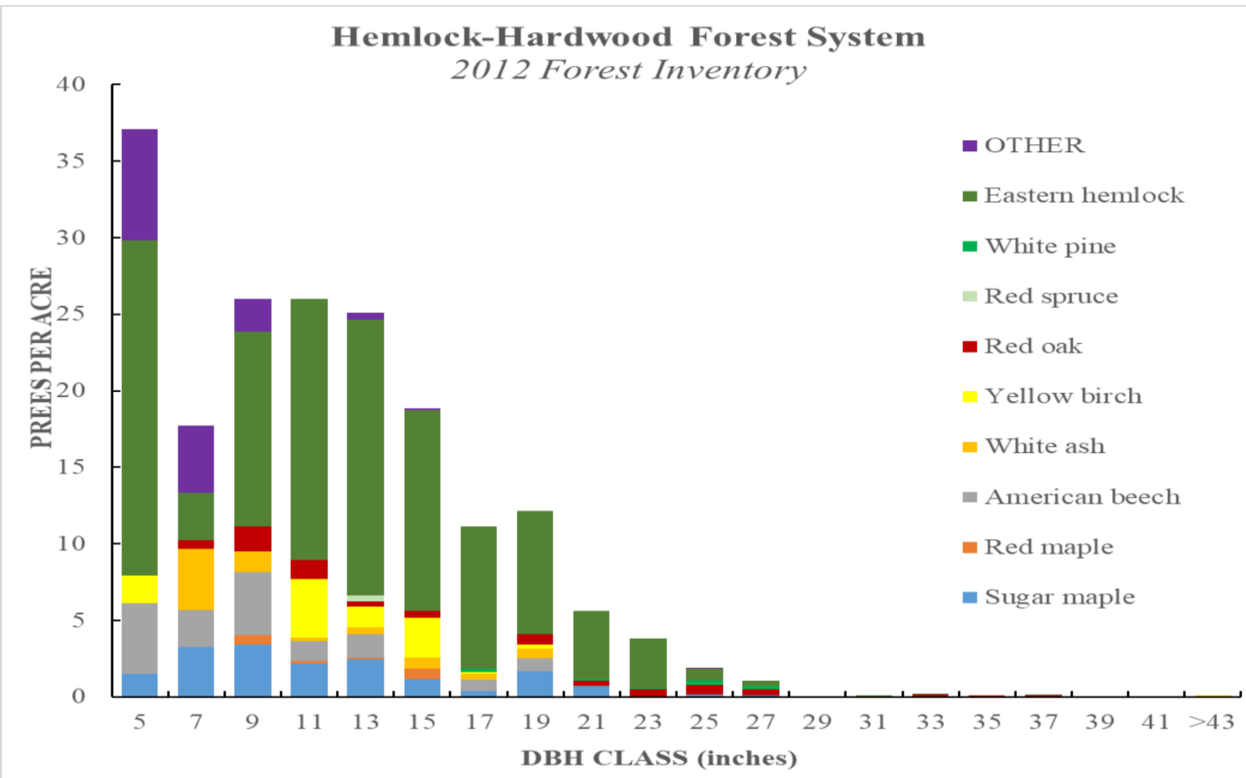


Figure 7: Hemlock-Hardwood forest system 2012 DBH distribution

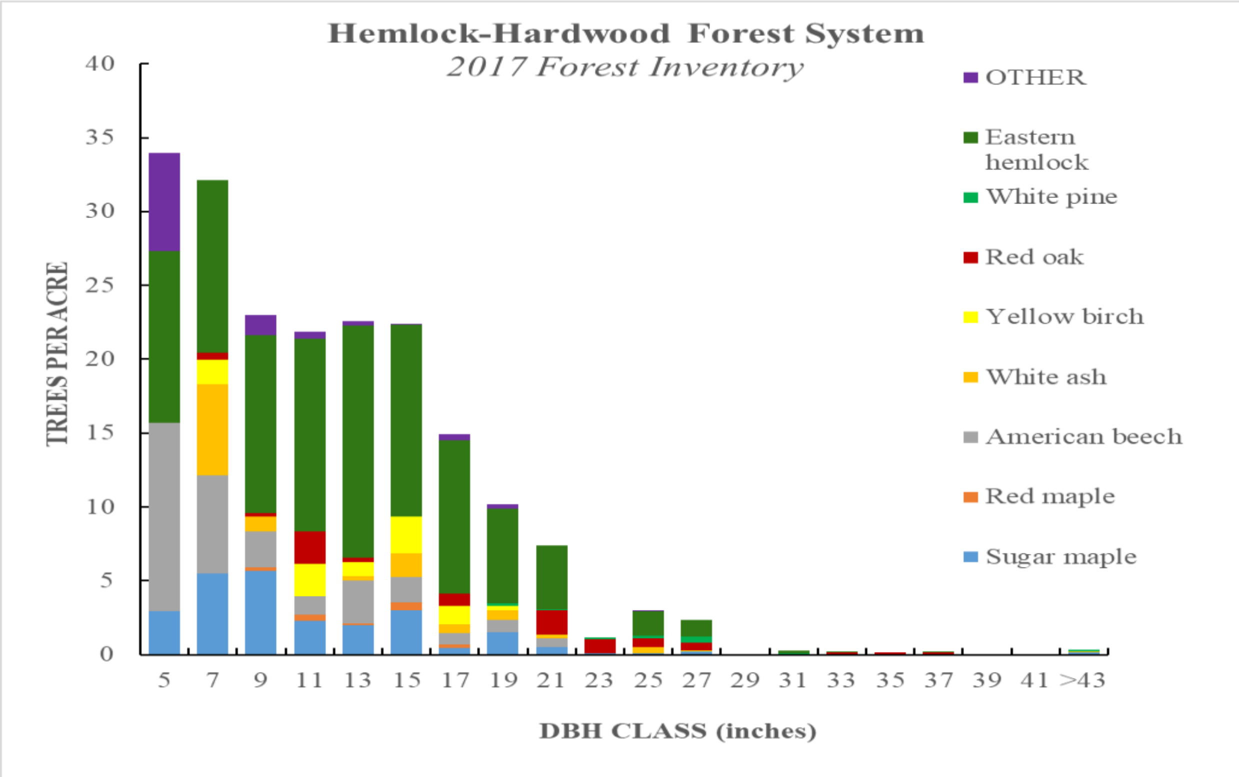


Figure 8: Hemlock-Hardwood forest system 2017 DBH distribution

Hemlock-Hardwood Overstory Analysis 2012-2017

Overstory Composition			
	2012		
Species	**Basal Area (ft^2/acre)**	**Trees Per Acre**	**Importance Value**
Eastern hemlock	102.67	61	69%
Sugar maple	11.07	7	8%
Yellow birch	6.93	7	6%
Northern red oak	9.87	4	5%
American beech	4.87	4	4%
White ash	4.67	3	3%
Other	6.92	3	5%
TOTAL	**147**	**89**	**100%**
	2017		
Species	**Basal Area (ft^2/acre)**	**Trees Per Acre**	**Importance Value**
Eastern hemlock	112.53	85	70%
Sugar maple	13.20	8	7%
Yellow birch	11.13	10	7%
Northern red oak	10.67	4	5%
American beech	6.20	5	4%
White ash	5.67	3	3%
Other	6.6	4	4%
TOTAL	**166**	**119**	**100%**

Table 22: Hemlock-Hardwood forest system overstory composition 2012 & 2017

Overstory Diversity and Adaptability 2012 & 2017					
Year	**Species Richness**	**Species Diversity**	**Species Evenness**	**trees/acre**	**Adaptability Score**
2012	13	1.24	0.48	89	3.25(L-M)
2017	12	1.20	0.48	119	3.21(L-M)

Table 22: Hemlock-Hardwood forest system overstory diversity and adaptability 2012 & 2017

Midstory Composition 2012			
Species	**Basal Area (ft^2/acre)**	**Trees Per Acre**	**Importance Value**
Eastern hemlock	4.60	29	31%
Sugar maple	3.60	10	16%
American beech	3.00	11	15%
Northern red oak	1.73	6	8%
White ash	1.53	5	8%
Hophornbeam	0.67	7	6%
Yellow birch	1.00	3	5%
Other	1.87	7	11%
TOTAL	**18**	**78**	**100%**
2017			
Species	**Basal Area (ft^2/acre)**	**Trees Per Acre**	**Importance Value**
Sugar maple	5.53	40	33%
Eastern hemlock	7.20	27	30%
American beech	3.40	14	15%
White ash	1.53	5	6%
Hophornbeam	0.67	7	5%
Northern red oak	1.60	3	5%
Yellow birch	1.00	3	4%
Other	1.07	1	2%
TOTAL	**22**	**100**	**100%**

Table 23: Hemlock-Hardwood forest system midstory composition 2012 & 2017

Midstory Diversity and Adaptability 2012 & 2017					
Year	**Species Richness**	**Species Diversity**	**Species Evenness**	**Trees/acre**	**Adaptability Score**
2012	12	2.05	0.83	78	3.82(M)
2017	10	1.71	0.74	100	4.13(M)

Table 24: Hemlock-Hardwood forest system midstory diversity and adaptability 2012 & 2017

REGENERATION ANALYSIS 2012 & 2017

Sapling Composition 2012 & 2017		
Species	**% Composition 2012**	**% Composition 2017**
American beech	48.4%	53.6%
Eastern hemlock	21.2%	19.7%
Hophornbeam	10.6%	10.8%
Striped maple	7.7%	7.4%
Yellow birch	2.0%	2.5%
Sugar maple	4.5%	2.3%
Other	5.6%	3.7%
TOTAL	**100.0%**	**100.0%**

Table 25: Hemlock-Hardwood forest system sapling composition 2012 & 2017

Sapling Diversity and Adaptability 2012 & 2017					
Year	**Species Richness**	**Species Diversity**	**Species Evenness**	**Saplings/acre**	**Adaptability Score**
2012	10	0.85	0.59	97	0.39(L)
2017	10	0.75	0.56	95	0.44(L)

Table 26: Hemlock-Hardwood forest system sapling diversity and adaptability 2012 & 2017

Seedling Composition 2012 & 2017		
Species	**% Composition 2012**	**% Composition 2017**
American beech	7.9%	20.5%
Choke cherry	4.6%	16.5%
Striped maple	12.9%	15.7%
Eastern hemlock	3.5%	13.8%
Northern red oak	48.6%	8.5%
Sugar maple	9.9%	7.4%
Red maple	0.0%	7.6%
Hophornbeam	3.8%	5.7%
Other	8.8%	4.3%
TOTAL	**100.0%**	**100.0%**

Table 27: Hemlock-Hardwood forest system seedling composition 2012 & 2017

Seedling Diversity and Adaptability 2012 & 2017					
Year	**Species Richness**	**Species Diversity**	**Species Evenness**	**Seedlings/acre**	**Adaptability Score**
2012	11	0.75	0.41	6271	2.11(L)
2017	12	0.98	0.61	2401	2.13(L)

Table 28: Hemlock-Hardwood forest system seedling diversity and adaptability 2012 & 2017

MITIGATION POTENIAL

Mitigation Potential - Biomass storage 2012 & 2017				
Year	**Living Biomass (tons/acre)**	**Standing Dead Biomass (tons/acre)**	**Downed Woody Debris (tons/acre)**	**Total Biomass (tons/acre)**
2012	74.8	5.6	9.9	90.3
2017	82.4	9.7	11.3	103.4

Table 29: Hemlock-Hardwood forest system mitigation potential

II: REGENERATION SURVEY RESULTS

Forest Regeneration Survey

Marsh-Billings-Rockefeller National Historical Park

Woodstock, Vermont

Matthias Nevins
Rubenstein School of Environment and Natural Resources
University of Vermont

July 11, 2018

INTRODUCTION

During the summer of 2017, a forest regeneration survey was conducted in 7 recently harvested and soon to be harvested stands in the Mount Tom Forest at the Marsh-Billings-Rockefeller National Historical Park. The goal of the survey was to assist in the evaluation of recent regeneration harvests and to determine the current understory conditions of stands that are designated to be treated in the next harvest entry.

METHODS

Stands that were included in the survey were selected by the forester for the Mount Tom Forest, Ben Machin, and MABI ecologist, Kyle Jones. Sampling plots were established systematically within each stand and stratified further within stands in order have plots located in recently harvested gaps. The density of plots was 1 plot per acre up to 10 acres. For every additional 5 acres, 1 plot was added. Therefore, a 15-acre stand would receive 11 plots. Plots were established using GIS and then the coordinates were transferred to a GPS unit for field location.

At each sampling point tree seedlings and saplings less than 4" diameter at breast height (DBH) were measured in 2 nested 1/100th and 1/1000th acre plots. Within the 1/100th acre plot, saplings greater than 1" and less than 4" DBH were tallied for each tree species. Within the 1/1000th acre plot, all seedlings less than 1" DBH were tallied for each tree species. Additionally, basal area (ft^2/acre) was measured from plot center using a 10 factor prism (angle gauge) and observations of competing vegetation, browse, invasive species, and sign of earth worm were also noted.

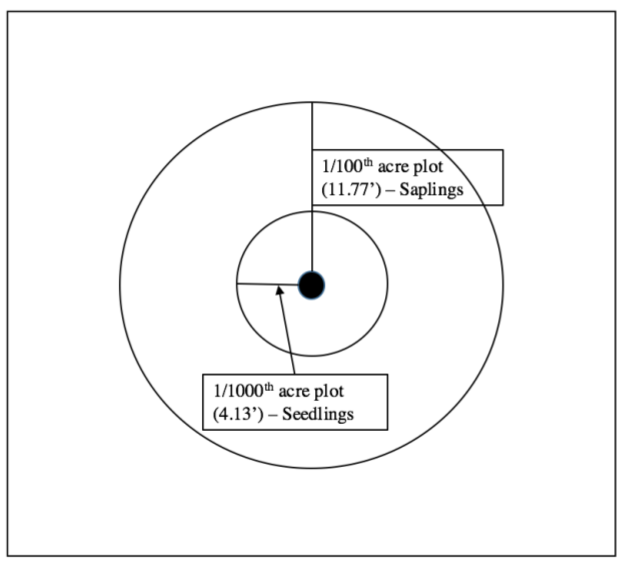


Figure 1: Plot design for regeneration survey

Tree density (#stems/acre) and percent composition was calculated for all saplings in each stand. Density, percent composition, and percent stocking was calculated for all seedlings. Species richness, Shannon's Diversity (H'), and Evenness was calculated for saplings and seedlings in each stand. Additionally, weighted mean adaptability and compatibility scores were calculated based on saplings and seedlings percent composition in each stand.

Adaptability and compatibility scores for each individual tree species were derived from the US Forest Service/Northeast Research Station's *Tree Atlas* (Iverson et al. 2008) and the recently published *Vulnerability Assessment and Synthesis* for New England (Janowiak et al. 2018). Adaptability scores are a metric used to describe an individual tree species ability to adapt and respond to environmental change. Individual tree species traits (shade tolerance, drought tolerance, regeneration ability, etc.) and characteristics related to how trees respond to disturbance (tolerance to insects and disease, browse, fire, harvests, etc.) are both taken into account (Kabrick et al. 2017). Scores range from 0-8.5 and stands with scores <3.3 indicate low adaptability, scores between 3.3 and 5.2 indicate moderate adaptability, and scores > 5.2 indicate high adaptability (Kabrick et al, 2017). Scores related to a species compatibility to projected future climate conditions was determined by using *Tree Atlas* habitat suitability assessments for individual species in New England based on two climate scenarios (PCM B1 and GFDL A1F1). Current importance values for each species (based on FIA plots) was compared to projected future importance values in years 2070-2099. Average stand scores < 0.8 are considered low compatibility, 0.8 -1.2 are moderate, and scores > 1.2 indicate high compatibility (Kabrick et al. 2017, Janowiak et al. 2018).

RESULTS

Results are presented below with a brief description of each stand a note on the measured basal area (ft^2/acre) and any additional observations. Sapling measurements are presented first for each stand followed by the seedling measurements. Diversity, adaptability, and compatibility are also presented for saplings and seedling. Adaptability and compatibility scores are interpreted with the notation; L: low, M: Moderate, and H: high. A table with the individual tree species score the interpretation of stand average scores are shown in the appendix (Table 1 and Table 2).

Stand 4:

Stand 4 is a 16.3-acre red pine plantation established in the early 1950s. An intermediate thinning was conducted in 2012. Average stand basal area is 81ft^2.acre.

STAND 4: SAPLINGS		
Species	***Trees Per Acre***	***% Composition***
ACSA	36	67%
FRAM	9	17%
OSVIR	9	17%
TOTAL	**55**	

Figure 2: Sapling density and composition

Richness	***Shannon's Diversity (H')***	***Evenness***	***Adaptability Score***	***Compatibility Score (Low Em)***	***Compatibility Score (High Em)***
3	0.87	0.79	0.43(L)	1.00(M)	1.03(M)

Figure 3: Sapling diversity, adaptability, and compatibility

STAND 4: SEEDLINGS			
Species	***Trees Per Acre***	***% Composition***	***% Stocking***
ACSA	4091	76	40
FRAM	545	10	50
PIST	273	5	20
POGR	91	2	10
PRPE	91	2	10
PRSE	91	2	10
QURU	182	3	10
TOTAL	**5364**		

Figure 4: Seedling density, composition, and stocking

Richness	*Shannon's Diversity (H')*	*Evenness*	*Adaptability Score*	*Compatibility Score (Low Em)*	*Compatibility Score (High Em)*
7	0.91	0.47	4.67 (M)	0.97 (M)	0.79(L)

Figure 5: Seedling diversity, adaptability, and compatibility

Stand 6:

Stand 6 is a 5.17-acre white pine stand that regenerated post abandonment of an agricultural field. This stand was treated with a group selection harvest in 2012. The stand basal area is 135 ft^2/acre.

STAND 6: SAPLINGS		
Species	***Trees Per Acre***	***% Composition***
ACSA	133	100%
TOTAL	**133**	

Figure 6: Sapling density and composition

Richness	*Shannon's Diversity (H')*	*Evenness*	*Adaptability Score*	*Compatibility Score (Low Em)*	*Compatibility Score (High Em)*
1	NA	NA	2.21(L)	0.90(M)	0.66(L)

Figure 7: Sapling diversity, adaptability, and compatibility

STAND 6: SEEDLINGS			
Species	***Trees Per Acre***	***% Composition***	***% Stocking***
ACSA	8000	41	50
FAGR	167	1	17
FRAM	9167	47	67
OSVIR	2333	12	67
TOTAL	**19667**		

Figure 8: Seedling density, composition, and stocking

Richness	*Shannon's Diversity (H')*	*Evenness*	*Adaptability Score*	*Compatibility Score (Low Em)*	*Compatibility Score (High Em)*
4	1.02	0.73	4.10(M)	1.08(M)	1.11(M)

Figure 9: Seedling diversity, adaptability, and compatibility

Stand 8:

Stand 8 is a 9.74-acre northern hardwood stand that was treated with a single tree selection harvest in 2011. Based on the regeneration survey, the basal area of the stand is 102 ft^2/acre. Signs of browse and earth worm was observed in 2 of the 10 plots.

STAND 8: SAPLINGS		
Species	*Trees Per Acre*	*% Composition*
ACSA	50	83%
FAGR	10	17%
TOTAL	**60**	

Figure 10: Sapling density and composition

Richness	*Shannon's Diversity (H')*	*Evenness*	*Adaptability Score*	*Compatibility Score (Low Em)*	*Compatibility Score (High Em)*
2	0.45	0.65	0.71(L)	0.92(M)	0.64(L)

Figure 11: Sapling diversity, adaptability, and compatibility

STAND 8: SEEDLINGS			
Species	*Trees Per Acre*	*% Composition*	*% Stocking*
ACSA	1500	35	30
ACSP1	200	5	10
FAGR	200	5	10
FRAM	1200	28	30
OSVIR	400	9	30
PIRU	800	19	10
TOTAL	**4300**		

Figure 12: Seedling density, composition, and stocking

Richness	***Shannon's Diversity (H')***	***Evenness***	***Adaptability Score***	***Compatibility Score (Low Em)***	***Compatibility Score (High Em)***
6	1.54	0.86	3.65(M)	0.97(M)	0.88(M)

Figure 13: Seedling diversity, adaptability, and compatibility

Stand 17:

Stand 17 is a 21-acre red pine stand that was planted in 1917 and has been treated most recently with a thinning in 2009. Stand level basal area is 111 ft^2/acre and browse was observed in one plot.

STAND 17: SAPLINGS		
Species	***Trees Per Acre***	***% Composition***
ACPE	33	10%
ACRU	33	10%
ACSA	133	41%
FAGR	78	24%
FRAM	22	7%
OSVIR	11	3%
PIST	11	3%
TOTAL	**322**	

Figure 14: Sapling density and composition

Richness	***Shannon's Diversity (H')***	***Evenness***	***Adaptability Score***	***Compatibility Score (Low Em)***	***Compatibility Score (High Em)***
7	1.59	0.82	1.26(L)	0.98(M)	0.74(L)

Figure 15: Sapling diversity, adaptability, and compatibility

STAND 17: SEEDLINGS			
Species	***Trees Per Acre***	***% Composition***	***% Stocking***
ACPE	778	8	33
ACRU	111	1	11
ACSA	4333	46	67
ACSP1	667	7	11
BEAL	222	2	11

FAGR	778	8	22
FRAM	1333	14	33
OSVIR	1000	11	22
PRSE	222	2	11
TOTAL	**9444**		

Figure 16: Seedling density, composition, and stocking

Richness	*Shannon's Diversity (H')*	*Evenness*	*Adaptability Score*	*Compatibility Score (Low Em)*	*Compatibility Score (High Em)*
9	1.70	0.77	4.35(M)	0.97(M)	0.86(M)

Figure 17: Seedling diversity, adaptability, and compatibility

Stand 18:

Stand 18 is a 22.2-acre white pine stand that was planted in 1905 and was most recently treated with a group selection harvest removing 40% of the basal area in 2015. The current basal area of the stand is 70ft^2/acre. Raspberry was observed to be thick within gaps, fern was observed in the understory and signs of deer scat and browse was also observed.

STAND 18: SAPLINGS		
Species	*Trees Per Acre*	*% Composition*
ACPE	33	16%
ACSA	8	4%
BEAL	17	8%
FAGR	50	24%
FRAM	25	12%
OSVIR	25	12%
PRPE	25	12%
PRSE	17	8%
VIAL	8	4%
TOTAL	**208**	

Figure 18: Sapling density and composition

Richness	*Shannon's Diversity (H')*	*Evenness*	*Adaptability Score*	*Compatibility Score (Low Em)*	*Compatibility Score (High Em)*
9	2.06	0.94	0.32(L)	0.96(M)	0.87(M)

Figure 19: Sapling diversity, adaptability, and compatibility

STAND 18: SEEDLINGS			
Species	***Trees Per Acre***	***% Composition***	***% Stocking***
ACPE	417	6	25
ACSA	1667	26	67
BEAL	1333	21	33
BELE	83	1	8
FAGR	250	4	8
FRAM	667	10	42
OSVIR	1250	19	42
PIRU	167	3	17
PIST	250	4	8
PRPE	250	4	8
QURU	83	1	8
TOTAL	**6417**		

Figure 20: Seedling density, composition, and stocking

Richness	***Shannon's Diversity (H')***	***Evenness***	***Adaptability Score***	***Compatibility Score (Low Em)***	***Compatibility Score (High Em)***
11	2.00	0.83	3.45(M)	1.00(M)	1.02(M)

Figure 21: Seedling diversity, adaptability, and compatibility

Stand 19:

Stand 19 is a 4.21-acre even-aged northern hardwood stand that was last treated in 2010 with single tree selection. Measured basal area for the stand is 70ft^2/acre.

STAND 19: SAPLINGS		
Species	***Trees Per Acre***	***% Composition***
FAGR	80	100%
TOTAL	**80**	

Figure 22: Sapling density and composition

Richness	***Shannon's Diversity (H')***	***Evenness***	***Adaptability Score***	***Compatibility Score (Low Em)***	***Compatibility Score (High Em)***
1	NA	NA	0.82(L)	1.00(M)	0.54(L)

Figure 23: Sapling diversity, adaptability, and compatibility

STAND 19: SEEDLINGS			
Species	***Trees Per Acre***	***% Composition***	***% Stocking***
ACPE	400	4	20
ACSA	1400	16	60
BEAL	2200	24	80
FAGR	3800	42	100
FRAM	200	2	40
OSVIR	600	7	20
PIST	200	2	20
QURU	200	2	20
TOTAL	**9000**		

Figure 24: Seedling density, composition, and stocking

Richness	***Shannon's Diversity (H')***	***Evenness***	***Adaptability Score***	***Compatibility Score (Low Em)***	***Compatibility Score (High Em)***
8	1.57	0.76	3.55(M)	0.97(M)	0.69(L)

Figure 25: Seedling diversity, adaptability, and compatibility

Stand 24:

Stand 24 is a 24.4-acre even-aged northern hardwood stand that was last treated in 2013 with single tree and group selection which removed 50 MBF of hardwood saw logs and 206 cords of low grade wood. Stand basal area is 98 ft^2/acre and earth worm was observed in 1 of the 13 plots sampled.

STAND 24: SAPLINGS		
Species	***Trees Per Acre***	***% Composition***
ACPE	7	5%
ACSA	7	5%
FAGR	43	32%
OSVIR	79	58%
TOTAL	**136**	

Figure 26: Sapling density and composition

Richness	***Shannon's Diversity (H')***	***Evenness***	***Adaptability Score***	***Compatibility Score (Low Em)***	***Compatibility Score (High Em)***
4	0.99	0.71	0.67(L)	1.09(M)	1.61(H)

Figure 27: Sapling diversity, adaptability, and compatibility

STAND 24: SEEDLINGS			
Species	***Trees Per Acre***	***% Composition***	***% Stocking***
ACPE	71	2	7
ACSP1	143	4	14
BEAL	143	4	14
ELDERB	500	16	36
FAGR	143	4	7
FRAM	1143	36	57
OSVIR	1071	33	36
TOTAL	**3214**		

Figure 28: Seedling density, composition, and stocking

Richness	***Shannon's Diversity (H')***	***Evenness***	***Adaptability Score***	***Compatibility Score (Low Em)***	***Compatibility Score (High Em)***
7	1.52	0.78	2.38(L)	1.11(M)	1.41(H)

Figure 29: Seedling diversity, adaptability, and compatibility

DISCUSSION

The results from the regeneration survey show positive regeneration conditions across the majority of stands. Sapling density ranged from 55 stems/acre in stand 4 to 322 stems/acre in stand 17. 41% of the stems in stand 17 were sugar maple. Stand 17 also showed high levels of diversity with sapling richness of 7 and a Shannon's Diversity Index (H') of 1.59. Stand 17 had the second highest diversity after stand 18 (Richness = 9, H'=2.06).

Seedling density ranged from 3,214 stems/acre (stand 24) to 19,667 stems/acre (stand 6). Seedling density and diversity was high across the majority of stands. Sugar maple, white ash, American beech, and hophornbeam are the most common species regenerating across the stands. Desirable densities of seedling are 1000 stems/acre. Sugar maple is at desirable densities in 6 of the 7 stands (All but stand 24). In contrast in stand 19 beech is dominating the sapling layer and is most abundant seedling layer (3,800 stems/acre). However, yellow birch and sugar maple are present in adequate densities (Yellow birch = 2,200 stems/acre, Sugar maple 1,400 stems/acres).

Adaptability and compatibility scores were presented here to add an additional lens through which to view the results. When assessed in the context of the species composition and diversity measures, adaptability and compatibility of each stand provide a metric for interpreting how these stands might respond or be resilient to a changing climate or other disturbances. Adaptability was Moderate to High for both saplings and seedlings across all stands. Stands 17 and 4 in particular stand out with high adaptability in the regeneration layer. Compatibility was Moderate to High for the low emissions scenarios across all stands and was Low to High for the high emissions scenarios across all stands. The high emissions scenario represents the most dramatic change is potential suitable habitat which would explain the Low values for some stands. Compatibility must be viewed in relation to adaptability. For example, sugar maple is predicted to see a decrease in suitability habitat under high emissions scenarios but has one of the highest adaptability scores (5.8). Therefore, while growing condition might be less favorable to sugar maple in the future, the inherent adaptive capacity of sugar maple makes it a highly resilient species.

These findings are presented without any detailed management recommendation because the results are meant to be used by the managers to help guide future prescriptions and evaluate the outcomes of past treatments.

ASSESS VULNERABILITY

__________________ Forest System

Stand/site:____

Potential Impacts	Adaptive Capacity	Vulnerability
		LOW MODERATE HIGH (Circle One) Comments:
	.	

Blank ASSESS Table

DEFINE MANAGEMENT GOALS		
____________________ Forest System Stand/site:____		
Desired future conditions	**Short-term goals**	**Long-term goals**

Blank DEFINE Table

EVALUATE MANAGEMENT		
___________________ Forest System **Stand/site: ____**		
Desired future condition:		
Management Goal based on desired future condition	**Management Challenges based on vulnerability**	**Management Opportunities based on vulnerability**

Blank EVALUATE table

IDENTIFY MANAGEMENT

___________________ Forest System

Stand/site:____

ADAPTATION STRATEGY	ADAPTATION APPROACH	ADAPTATION TACTICS	BENEFITS OR DRAWBACKS/BARRIERS
*See menu	*See menu		

Blank IDENTIFY table

MONITOR MANAGEMENT		
___________________ Forest System Stand/site: ____		
Desired future condition:		
Long-Term Management Goal	**Monitoring Benchmark**	**Implementation**

Blank MONITOR table

MENU OF ADAPTATION STRATEGIES AND APPROACHES	
Strategy 1: Sustain fundamental ecological function	**Strategy 6: Increase ecosystem redundancy across the landscape.**
1.1. Reduce impacts to soils and nutrient cycling.	6.1. Manage habitats over a range of sites and conditions
1.2. Maintain or restore hydrology	6.2. Expand the boundaries of reserves to increase diversity
1.3. Maintain or restore riparian areas	**Strategy 7: Promote landscape connectivity.**
1.4. Reduce competition for moisture, nutrients, and light	7.1. Reduce landscape fragmentation
Strategy 2: Reduce the impacts of biological stressors.	7.2. Maintain and create habitat corridors through reforestation and restoration
2.1. Maintain or improve the ability of forests to resist pests and pathogens	**Strategy 8: Maintain and enhance genetic diversity**
2.2. Prevent the introduction and establishment of invasive plant species and remove existing invasive species	8.1. Use seeds, germplasm, and other genetic material from across a greater geographic range
2.3. Manage herbivory to promote regeneration of desired species	8.2. Favor existing genotypes that are better adapted to future conditions
Strategy 3: Reduce the risk of long-term impacts of severe disturbances	**Strategy 9: Facilitate community adjustments through species transitions.**
3.1. Alter forest structure or composition to reduce risk of severity of wildfire	9.1. Favor or restore native species that are expected to adapted to future conditions
3.2. Establish fuel breaks to slow the spread of catastrophic fire	9.2. Establish or encourage new mixes o native species
3.3. Alter forest structure to reduce severity or extent of wind and ice damage	9.3. Guide changes in species composition at early stage of stand development
3.4. Promptly revegetate sites after disturbance	9.4. Protect future-adapted seedling and saplings
Strategy 4: Maintain or create refugia.	9.5. Disfavor species that distinctly maladapted
4.1. Prioritize and maintain unique sites.	9.6. Manage fore species and genotypes with wide moisture and temperature tolerances
4.2. Prioritize and maintain sensitive or at-risk species or communities	9.7. Introduce species that expected to be adapted to future conditions
4.3. Establish artificial reserves for at-risk and displaced species	9.8. Move at-risk species to location that expected to provide habitat
Strategy 5: Maintain and enhance species and structural diversity.	**Strategy 10: Realign ecosystem after disturbance**
5.1. Promote diverse age classes	10.1. Promptly revegetate sites after disturbance
5.2. Maintain and restore diversity or native species	10.2. Allow for areas of natural regeneration to test future-adapted species
5.3. Retain biological legacies	10.3. Realign significantly disrupted ecosystems to meet expected future conditions
5.4. Establish reserves to maintain ecosystem diversity	

Menu of adaptation strategies and approaches (Swanston et al. 2016)

IV: Adaptability scores

SPECIES TABLE					
Species Code	***Common Names***	***Latin Names***	***Adaptability Score***	***Compatibility Score // current:future IV (2070-2099)***	
				PCMB1(LOW)	***GFDL.A1F1(High)***
QURU	northern red oak	Quercus rubra	5.4	1.429	2.193
BEAL	yellow birch	Betula alleghaniensis	3.4	0.859	0.358
PIRE	red pine	Pinus resinosa	3.9	1.005	2.514
OSVIR	hophornbeam	Ostrya virginiana	4	1.191	2.382
PIAB	Norway spruce	Picea abies	3.3*	0	0
ACSA	sugar maple	Acer saccharum	5.8	0.909	0.657
PIRU	red spruce	Picea rubens	4.3	0.691	0.341
TSCA	eastern hemlock	Tsuga canadensis	2.7	1.137	0.909
PIST	eastern white pine	Pinus strobus	3.3	1.039	0.904
FAGR	American beech	Fagus grandifolia	3.6	0.98	0.54
PISY	Scots pine	Pinus sylvestris	3.3*	NA	NA
BELE	sweet birch	Betula lenta	3.2	1.712	2.644
JUCI	butternut	Juglans cinerea	2.3	1.206	0.529
ACRU	red maple	Acer rubrum	8.5	1.082	0.887
POTR	quaking aspen	Populus tremuloides	4.7	0.875	0.574
FRAM	white ash	Fraxinus americana	2.7	1.196	1.199
TIAM	American basswood	Tilia americana	4.6	0.94	1.68
ULAM	American elm	Ulmus americana	4	1.167	2.418
POGR	Bigtooth aspen	Populus grandidentata	5.1	1.031	1.009
BEPA	paper birch	Betula papyrifera	3.4	0.761	0.269
AMELA	service berry	Amelanchier spp.	3.4	NA	NA
PRSE	black cherry	Prunus serotina	3	1.122	1.367
ROPS	black locust	Robinia pseudoacacia	3.8	2.594	15.031
LARIX	larch	Larix laricina	3.3	NA	NA
ACPE	striped maple	Acer pensylvanicum	5.1	0.903	0.487
ACSP1	Mountain maple	Acer spicatum	5.9	0.632	0.081
PRPE	Pin cherry	Prunus pensylvanica	4.2	0.863	0.589
ELBERB		Sambucus nigra	3.2*	1*	0.9*

Table 1: Species list with adaptability and compatibility scores

COMPATIBILITY SCORE		ADAPTABILITY SCORE	
LOW	**< .8**	LOW	**< 3.2**
MODERATE	**0.8-1.2**	MODERATE	**3.2-5.2**
HIGH	**>1.2**	HIGH	**>5.2**

Table 2: Compatibility and adaptability score interpretation

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