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Reexamining the Utility of Existing Climate Adaptation Frameworks Through Application on a Northern Forest

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REEXAMINING THE UTILITY OF EXISTING CLIMATE ADAPTATION FRAMEWORKS THROUGH APPLICATION ON A NORTHERN FOREST

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Abstract

A review of the literature reveals the strengths and limitations of various climate adaptation frameworks and illuminates a general path by which a type of adaptation can be achieved. A number of useful frameworks exist but the number of independent case studies demonstrating the adaptation process in a detailed manner is much more limited. Additionally, components of the various adaptation processes can often seem vague and concepts such as adaptability ill-defined. For land managers approaching climate adaptation independently can be difficult, particularly in the areas of goal creation and vulnerability assessment. Within frameworks where user-defined adaptation goals dictate whether or not adaptability will be achieved, providing guidance on definition of these concepts is particularly important. To explore and improve the usability of climate adaptation concepts we applied them on Michigan Technological University's Ford Forest. We reviewed the literature on climate change adaptation and applied the knowledge gained to the creation of a climate change adaptation-focused management plan. We assessed the difference between business-as-usual management and climate adaptation and identified where either had occurred in order to 1) better define climate change adaptation operationally, and 2) demonstrate how and where it had occurred within our plan. In doing so we hope to demonstrate explicitly methods for climate change adaptation planning and expand the definition of climate adapted systems.

Through application of the principles of these frameworks, we have found that identifying priority values early in the management planning process while recognizing future climate uncertainty will improve the ability to generate meaningful, effective management actions. Recognition of organizational limitations and potential flaws in the decision-making process can help to improve planning outcomes. We have proposed a logical way to assess decision-making outcomes in a climate adaptation planning context. Vulnerability indices are useful for identifying areas of risk in a forest, but a general focus on adaptability is still necessary to respond to future climate uncertainty. Operationally, climate change adaptation refers to the broad category of planning and management measures undertaken to protect specific values from the negative effects of anthropogenic climate change.

1 Introduction

Foresters in an era of global change are faced with the problem of determining how to alter management in order to maintain the ability of human beings to derive value via ecosystem services from forested ecosystems. Doing so is generally regarded as involving identification of which components of the ecosystem will be subject to change from the impacts of a warming climate and what actions are necessary to prevent or respond to such changes. Appropriate responses will be dependent on regional and ownership contexts and will vary based on organizational goals and values. Making use of a growing body of climate adaptation literature serves to expedite the process and prevent individual forest management units from having to solve large-scale and resource intensive research problems.

Climate variables are major drivers of species occurrences and assemblages at a given location. Changes in climate at a local and regional scale will result in varying changes to forests and associated tree populations (Brubaker 1986; Dynesius and Jansson 2000; Rehfeldt et al. 2014b, a). Species ranges have historically shifted with past changes in climate (Prentice et al. 1991; Dynesius and Jansson 2000) but rapid shifts brought about by anthropogenic climate change will likely outpace the ability of tree species to expand their ranges or migrate in many areas, particularly in northeastern forests (Burrows et al. 2011; Sittaro et al. 2017). Species which are unable to adapt or migrate under new climate regimes will be reduced as components of the landscape or face local extinction (Aitken et al. 2008; Canham and Thomas 2010). Given the potential for climate change to outpace much of forest ecosystems' self-organizational capacity, intentional, directed climate change adaptation is necessary to maintain ecosystem services.

A review of the literature reveals the strengths and limitations of various climate adaptation frameworks and illuminates a general path by which a type of adaptation can be achieved. A number of useful frameworks exist but the number of independent case studies demonstrating the adaptation process in a detailed manner is much more limited. Additionally, components of the various adaptation processes can often seem vague and concepts such as adaptability ill-defined. For land managers, approaching climate adaptation independently can be difficult, particularly in the areas of goal creation and vulnerability assessment. Within frameworks where user-defined adaptation goals dictate whether or not adaptability will be achieved, providing guidance on definition of these concepts is particularly important.

To explore and improve the usability of climate adaptation concepts we applied them on Michigan Technological University's Ford Forest. The goal of this work is to demonstrate the conception and application of an expanded decision-making process for climate management planning in an era of climate change, and to provide some means for evaluation of this process in order to guide future improvements. We review the literature on climate change adaptation in order to develop an adaptation process that could be applied to all steps of management planning. We expand upon and demonstrate how we applied the knowledge gained to the creation of a climate change adaptation-focused management plan to test these concepts. We apply a management science perspective to improve the planning process and create a new method for evaluating climate adaptation concepts within a plan. In addition, to better define climate change adaptation operationally, and demonstrate how and where it had occurred within our plan. We assess the difference between business-as-usual management and climate adaptation and identify where either has occurred. In doing so we hope to demonstrate explicitly methods for climate change adaptation planning and expand the definition of climate adapted systems.

1.1 Overview of Adaptation Frameworks

Over a thousand scientific papers exist on climate change impacts and adaptation options within the forestry sector (Keenan 2015) but few of these constitute *adaptation frameworks*. Here, an adaptation framework is distinguished as being process-based and seeking to guide the translation of scientific knowledge on techniques for climate change adaptation to an integrated strategic approach to adapting a landscape in preparation for the effects of climate change. A number of climate change frameworks exist with varying strengths and limitations based on their intended purposes and institutional context as well as on the geographic location in which they were developed. Here, we have performed a guided review of these frameworks in order to inform adaptation on our own land base.

A key component in climate change adaptation versus other forms of forest and natural resource management is the idea of planning for a range of uncertain futures rather than a single possible outcome as a result of an inability to perfectly predict future climate in a given place (Millar et al. 2007). This limitation, inherent to climate change adaptation planning, is often handled with the inclusion of climate adaptation concepts in an adaptive management framework (e.g. Peterson et al. 2011; Gauthier et al. 2014; Janowiak et al. 2014b; Edwards et al. 2015; Schmitz et al. 2015). However, in some cases the adaptation framework is itself a modified adaptive management framework as is the case with the Climate Change Response Framework (CCRF) (Swanston and Janowiak 2012; Janowiak et al. 2014b). Others explicitly identify the need for adaptive management and incorporate it as part of their framework, such is the case with the multiple systems based around the findings of the Canadian Council of Forest Ministers (CCFM) as well as the Adaptation Partners Framework (APF) in the Western United States (Peterson et al. 2011; Gauthier et al. 2014; Edwards et al. 2015; Schmitz et al. 2015). In either case, the concept of adaptive management is integral to climate change adaptation.

Some frameworks do not explicitly incorporate adaptive management. Instead, uncertainty and a multi-scenario future is handled through a focus on adaptability or resilience to a more specific range of predicted disturbances (e.g. Colloff et al. 2016;

Keskitalo et al. 2016; Vilà-Cabrera et al. 2018). Another approach would be to maximize organizational readiness and seek to minimize uncertainty to the extent possible to inform climate change adaptation decision making (Yousefpour et al. 2017). However, the conditions necessary for such a rigorous decision-making process rarely exist in public natural resource management organizations (Boston and Bettinger 2001). Ogden and Innes (2007), which serves as much of the basis for the Canadian Council of Forest Ministers System, focuses heavily on the development of a broad array of objectives for climate change adaptation.

The national or regional context is an important consideration with the various frameworks. Canadian forest land is largely state run and based around widely applied principles of sustainable forest management (Halofsky et al. 2018). As such, the goal of climate change adaptation in Canada is maintenance of the principles of sustainable forest management (Ogden and Innes 2007; Edwards et al. 2015). In the United States there is a split between climate change adaptation in the eastern and western regions. In the east, the Climate Change Response Framework (Swanston and Janowiak 2012; Janowiak et al. 2014b; Swanston et al. 2016) focuses mainly on adaptation on private lands (Ontl et al. 2018) making use of region-specific decision-support models such as the TreeAtlas (Iverson et al. 2008). In the Western United States, owing to a different pattern of land ownership, the Adaptation partners framework (Peterson et al. 2011) is largely agency-focused and deals with adaptation planning on federal land. The APF is also heavily focused on organizational readiness as it is primarily deployed at the federal agency level. Schmitz et al. (2015), another proposed framework in the United States, is designed for the expressed purpose of biodiversity protection with a focus on large organizations such as federal or state agencies.

Outside of North America a number of frameworks exist with designs that reflect their regional contexts. Colloff et al. (2016) and Vilà-Cabrera et al. (2018) from Australia and the Mediterranean (Spain) respectively, were both designed within dryland ecosystems where fire is a major concern. Instead of adaptive management, both are concerned with responding to increased disturbance, primarily more frequent and severe fire. The former does this with a comprehensive analysis of ecosystem services and adaptation pathways while the latter focuses heavily on strategies to improve resilience. Swedish forestry is more heavily focused on provisioning services and commodity production, a result of the Swedish approach defined in the 1993 Forest Act: Freedom under responsibility. The Swedish Commission on Climate Change Vulnerability is focused largely on managing for a specific set of increased disturbances, mainly windthrow, and intense management interventions designed to maintain the flow of goods and services. The Swedish model is designed around responding to threats and opportunities associated with change with limited institutional adjustments (Keskitalo et al. 2016). Yousefpour et al. (2017) suggests a framework for climate change which seeks to update attitudes to the necessity of adaptation and to provide guidance for robust-decision making (Radke et al. 2017) for broad application to the wide swath of forest management issues and socioeconomic contexts across Europe. It focuses less on specific recommendations and more on how adaptation options are composed and selected.

Many key similarities can be found between the processes proposed by the Canadian Council of Forest Ministers, those proposed by the U.S. Forest service (Halofsky et al. 2016), and others. The process typically starts with some analysis of the institution of interest as well as a period for definition of the area of interest and goals and objectives. This is followed by some form of vulnerability assessment or analysis of potential climate change impacts. After this, adaptation options are brainstormed and evaluated, implementation occurs, and monitoring is used to determine efficacy and, theoretically, course correction occurs (Peterson et al. 2011; Gauthier et al. 2014; Janowiak et al. 2014b; Edwards et al. 2015) . Even those frameworks not explicitly rolled into adaptive management can still provide critical decision support as well as suggested actions at various stages of the process. Reviewed here is the major literature on the various components of the climate change adaptation process.

1.1.1 Defining the Problem and Setting Goals

Definition of timeframes and areas of interest is considered a first step in multiple frameworks (Peterson et al. 2011; Janowiak et al. 2014b; Edwards et al. 2015). In terms of goal definition, frameworks can be sorted into three groups: those who identify goal definition as a component of the process, those with preexisting goals based on a more uniform national system of forest management, and those that do not consider goal definition or that regard climate change adaptation as a goal in and of itself. Within the Adaptation Partners Framework, goal setting can occur multiple times as a matter of scale in order to serve the larger goal of responding to climate change (Peterson et al. 2011). The Climate Change Response Framework explicitly identifies goal definition as a starting point to a climate focused adaptive management process. The process of the CCRF is driven by user-defined goals wherein climate change adaptation is both an end and a means to an end rather than a goal in and of itself. In this way, the CCRF could be applied to any set of management goals, although filtration of goals and objectives for feasibility is a step following vulnerability assessment. Filtration of goals is seen as a critical step to integrating adaptation planning and so guidance on goal creation is limited (Swanston and Janowiak 2012; Janowiak et al. 2014b). Sandström et al. (2016) delineates a useful way in which users can define desired future conditions (DFC's) within the context of climate change. The process, known as backcasting, involves discussion of a desired future state followed by conceptually working backwards to identify climate related and other obstacles to achieving DFCs.

The Canadian Council of Forest Ministers system is broadly applicable but assumes a predefined goal of sustainable forest management (SFM) as defined by the CCFM (Working Group on Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests 1995). The list of adaptation options used by the CCFM was conceived by Ogden and Innes (2007) and assumes SFM as the overarching goal of adaptation, and lists options in terms of SFM criteria and indicators. Williamson and Edwards (2014) provide a guide for updating criteria and indicators associated with sustainable forest management in order to improve relevance and feasibility within the context of global change. Some frameworks assume biodiversity or continuity of ecosystem services to be an overarching goal (Schmitz et al. 2015; Keskitalo et al. 2016), while some assume resilience to be the primary goal as an end point for adaptation (Colloff et al. 2016; Vilà-Cabrera et al. 2018). These former approaches can still provide useful insights and methods for climate change adaptation.

1.1.2 Vulnerability Assessment

The vast majority of climate change adaptation research is focused on evaluation of impacts and vulnerability (Keenan 2015). Much of this literature is concerned with continental or global-scale predictions but a portion pertains to making and utilizing local-scale predictions. Vulnerability assessment, as a step in the climate adaptation process, is explicitly designed into multiple frameworks (Ogden and Innes 2007; Peterson et al. 2011; Gauthier et al. 2014; Janowiak et al. 2014b; Edwards et al. 2015). Conceptually, some form of assessment or discussion of climate change impacts is included in most of the literature that refer to themselves as frameworks. More procedural means for assessing vulnerability are delineated in some frameworks along with supporting literature.

One approach, The Ecosystem Vulnerability Assessment Approach (EVAA) (Brandt et al. 2017), a component of the CCRF, is a method for the determination of regional-scale vulnerability using climate and landscape modelling. The process involves evaluation of current and future drivers, stressors and dominant species as well as potential interactions of climate driven factors. Vulnerability is determined based on a combination of adaptive capacity and potential climate change impacts. Finally, uncertainty is discussed and agreed upon for an overall determination of climate change vulnerability and uncertainty at a regional level. For the Northwoods assessment (Janowiak et al. 2014a) Landis-II, TreeAtlas, and PnET-CN were used to create inputs calibrated with 2 climate scenarios representing a low and high emissions scenario. The output report detailed general vulnerabilities as well as species specific predictions of changes in suitable habitat under each scenario. Climate inputs are statistically downscaled for these assessments to help predict ecological outcomes at a scale that accounts for topographical and other local factors, but the resolution of these inputs is limited to around 6 square miles. As such, methods for interpreting these outputs in a way that is useful at finer scales are necessary. Janowiak et al. (2017) devises a way, known as the Climate Risk Metric (CRM), to use region-level species predictions from TreeAtlas to determine stand level climate risk using importance values on a stand-by-stand basis. Relative dominance in terms of importance value is calculated for each species followed by the proportion of each stand made up of total at risk overstory species for each emissions scenario. Outputs of the CRM provide a starting point to assess local drivers of decline.

The CCFM approach views vulnerability in terms of the vulnerability to climate change of the ability to achieve specific forest management objectives. Vulnerability is comprised of climate change impacts and the adaptive capacity of the system and impacts are comprised of exposure to climate change and system sensitivity (Edwards et al.

2015). The CCFM emphasizes the use of the best available data rather than a specific set of informative criteria. A combination of qualitative and quantitative information is used including inventory and climate data for both current conditions and projection as well as practitioner and manager expertise to capture the on-the-ground perspective. Analysis of plausible alternative future scenarios allows planners to account for future climate uncertainty. This method involves using both various data driven projections and observations as well as manager and public input to construct a range of reasonable future narratives to capture the swath of possibilities for which planning is necessary (Price and Isaac 2012). Gauthier et al. (2014), an application of the CCFM framework which expands upon many of its principles, divides both vulnerability assessment and adaptation between the human and biophysical subsystems where the former refers to the institutional capacity and economic context of forest management and the latter refers to the non-human components of the ecosystem.

1.1.3 Adaptation Options

The general goal of adaptation options across all frameworks is to increase the ability of a system to resist or respond to the negative effects of climate change. Adaptation options cover a broad range of activities and objectives but are generally sorted into three categories: reducing stressors and sensitivity to enhance resistance, promoting resilience, or transitioning partially or entirely to a new future adapted system (Millar et al. 2007; Gauthier et al. 2014).

Defining resistance and resilience and distinguishing between the two is essential for their conceptual utility as implied objectives of climate change adaptation. Vilà-Cabrera et al. (2018) recognizes the connection between the two concepts defining resilience as a function of both resistance and the ability of a system to respond to disturbance. Here we define disturbance as a discrete or ongoing event leading to changes in the underlying conditions of an ecosystem resulting in a chronic to permanent change in the state of the system. Press disturbances refer to long term, ongoing events impacting a system such as drought or, more broadly, climate change. Pulse disturbances refer to discrete events (Duveneck and Scheller 2016). Duveneck and Scheller (2016) define the two concepts in relation to increased disturbance under climate change where resistance is the ability to withstand pulse disturbance and resilience is the ability to withstand the interacting effects of both press and pulse disturbance. A number of definitions of resilience exist, many of which make the mistake of equating resilience to biodiversity in terms of species richness, but in general resilience must be defined in the context of a specific desired outcome in order to be useful as a concept in forest management (Puettmann 2011). DeRose and Long (2014) define resistance and resilience in terms of scale and measurability of specific attributes where resistance is the influence of structure and composition on the severity of disturbance and resilience is the influence of disturbance on subsequent composition. The two concepts are scaled by composition of a stand versus composition of stands in a landscape. The long accepted definition posited by Holling (1973) refers to resilience as the ability of a system to absorb change and stability as what is defined in the contemporary literature as resilience: the ability of a system to return to an equilibrium state following temporary disturbance. The key idea behind resilience is that a resilient system can absorb the effects of change or disturbance and maintain or return to a defined state. As such, resilience as a concept in climate adaptation is focused on the persistence of a system (Swanston et al. 2016). Millar et al. (2007) defines resistance and resilience in terms of categorization of adaptation options where resistance pertains to management techniques that serve to resist or delay the negative effects of climate change and resilience refers to those options that allow systems to return to a previous state following disturbance either on their own or through minimal intervention. Transition treatments are appropriate in systems which lack resilience and where resistance to change is no longer feasible. They constitute a recognition of inevitable change and a facilitation of that change in order to establish a new, resilient system (Gauthier et al., 2014; Janowiak et al., 2014; Millar et al., 2007; Nagel et al., 2017; Swanston & Janowiak, 2016).

1.1.3.1 Promoting Resistance

Resistance, as a category of adaptation options, refers to those actions aimed at protecting relatively valuable resources in the short term by forestalling the negative effects of climate change through intense management (Millar et al. 2007). Resistance adaptation options are typically structure-focused and place a heavy emphasis on preventing or minimizing disturbances such as fire, windthrow, or insect attack (Millar et al. 2007). In this way, it could be argued that resistance adaptation options are a response to climate change, but not necessarily an attempt at adaptation. The distinction is dependent on intent as many resistance options constitute business-as-usual management with a climate focus. Implementation of resistance actions generally requires an acceptance that their efficacy will become limited in the future (Millar et al. 2007). The major tenants of resistance in forest ecosystems are protection against the impacts of biological stressors and protection from physical disturbance; the former is often achieved through intense management interventions where the latter is done through alteration of forest structure and composition (Ogden and Innes 2007; Butler et al. 2012; Gauthier et al. 2014; Janowiak et al. 2014b).

Strategic management of biological stressors involves active control of invasive species as well as prevention of their establishment (Butler et al. 2012; Gauthier et al. 2014). Emphasis is placed on maintenance and enhancement of forests' ability to resist pests and pathogens including adjusting harvest schedules by shortening rotations and reducing disease losses through sanitation cuts (Ogden and Innes 2007; Roberge et al. 2016). A general focus on stand vigor is emphasized (Butler et al. 2012; Edwards et al. 2015).

Focusing on harvest and regeneration techniques for diversity on a landscape scale could help alter disturbance patterns and prevent catastrophic scale occurrences (Gauthier et al. 2014; Vilà-Cabrera et al. 2018). Churchill et al. (2013) proposes the "Individuals Clumps and Openings" (ICO) method, in which reference conditions and climate projections are used to design silvicultural treatments which restore mosaic conditions in fire-prone systems. Fuel breaks are an effective way to prevent catastrophic losses from fire (Butler et al. 2012) as well as the use of prescribed burning to manage understory structure and fine fuels associated with harvest (Gauthier et al. 2014; Roberge et al. 2016; Vilà-Cabrera et al. 2018). Prevention of catastrophic fire and windthrow events can also be achieved through the use of silvicultural techniques designed to increase stand vigor by lowering vulnerability to drought and insect attack (Gauthier et al. 2014). For example thinning in pine systems to achieve lower densities could reduce susceptibility to drought and promote resistance to insect attack (D'Amato et al. 2013; Bottero et al. 2017) and could additionally reduce the intensity of any potential fire (Vilà-Cabrera et al. 2018). In northern hardwood stands, frequent and low-intensity uneven-aged silviculture (FLI) can be used to enhance or maintain stand vigor while still providing a sustained yield of high quality timber (HQT) by maintaining a specific basal area of HQT while still thinning the stand and allowing for extraction of merchantable material (Nolet et al. 2014). With increasing temperature and shifts in precipitation patterns under a changing climate, balancing thinning for stand vigor and its associated changes in microclimate and their effects on regeneration will be increasingly important (Puettmann 2011).

1.1.3.2 Promoting Resilience

As mentioned above, there are a number of definitions of ecosystem resilience making management towards the goal of resilience difficult to target and achieve. Resilience treatments seek to improve an ecosystem's ability to recover from disturbance and to consistently provide ecosystem services (Millar et al. 2007). In this way, resilience treatments are focused on the stability (Holling 1973) of the underlying factors supporting ecosystem services in a given system and the persistence of that system. Puettmann (2011) suggests management of forests as complex adaptive systems as a response to global change. This is achieved through a focus on resilience and adaptability, where the former is defined as the ability to efficiently deliver desired ecosystems services and the latter is the ability of a system to adapt to change in order to maintain resilience. Achievement of both is done through management of tradeoffs between these two values and productivity. In short, commodity production may be reduced in the short term in order for its preservation along with a range of values in the long term. Resilience options may seek to promote a system's ecological "buffering" ability wherein species and functional diversity represent a "stacking of the deck" against global change. Here, the terms "ecological buffering" or an ecosystem's "buffering capacity" are adapted from Swanston and Janowiak (2016) and refer to the redundancy of ecological function provided by a higher species richness (Peterson et al. 1998). This ecological redundancy provides for response diversity (Elmqvist et al. 2003), theoretically improving a given ecosystem's ability to withstand or recover from various disturbances via a greater variety of individual species' responses to perturbation (e.g. seed banking vs sprouting, fire survival vs serotiny, etc.).

One way to achieve the broad objectives of resilience, adaptability and buffering capacity is to seek to promote or increase species and structural diversity (Butler et al.

2012). Maintenance of a range of seral stages at a landscape scale has been identified as one way to avoid ecosystem collapse by managing for conservation of a range of critical life stages (Lindenmayer et al. 2016). Restoration of the diversity of native trees, where it has been lost, is essential as well as efforts to plant broader ranges of tree species (Butler et al. 2012; Gauthier et al. 2014). Regeneration of degraded areas will allow for maximization of the buffering capacity of forest systems (Gauthier et al. 2014). Brang et al. (2014) assessed the suitability of close-to-nature silviculture (group-selection, single-tree, and shelterwood) for improving adaptive capacity to climate change and found that they were moderately compatible, depending on the specific system and specifics of implementation.

Where possible, returning fire to traditionally fire-adapted systems can help maintain resilience and prevent catastrophic losses (Butler et al. 2012; Gauthier et al. 2014). Jack pine systems in Michigan’s Upper Peninsula have generally been associated with fire-driven regeneration (Nyamai et al. 2014; Tardif et al. 2016). The use of prescribed burns has the potential to enhance regeneration in jack pine stands where mortality from insects or other stressors becomes an issue (Sharpe et al. 2017). Harvesting and burning slash piles has possible benefits in terms of growth and available nutrients in jack pine (Thorpe and Timmer 2005) though the combination of harvest and fire, constituting short-interval repeat disturbances, has been shown to hamper regeneration and increase the prevalence of early successional colonizers in regenerating stands (Pidgen and Mallik 2013). Maintaining slash could also have benefits in terms of microclimate which could create more ideal conditions for regeneration (Wiensczyk et al. 2011).

Ecosystem redundancy, or the redundancy of particular ecosystem types on the landscape, can be utilized to enhance resilience at a landscape scale (Butler et al. 2012). This can be achieved through maintenance of habitat types across gradients and scales and across a range of conditions and sites (Ogden and Innes 2007; Butler et al. 2012; Gauthier et al. 2014). Protection of functional groups as well as diversity at the genetic, species and landscape scales will be of importance (Gauthier et al. 2014; Lindenmayer et al. 2016). Promotion of mixed forests can also enhance ecosystem resilience (Vilà-Cabrera et al. 2018). Switching monocultures to mixed-species stands can significantly enhance buffering capacity (Puettmann 2011) thinning and underplanting can be effective at enhancing diversity where it has been lost in order to promote mixed forest types (Parker et al. 2001). Minimizing landscape fragmentation through careful planning of roads, use of reserves, and protection of corridors can also serve to enhance redundancy (Butler et al. 2012; Gauthier et al. 2014).

Finally, enhancing genetic diversity is an important method for promote the buffering capacity of an ecosystem in order to enhance resilience (Butler et al. 2012). Use of seeds and propagules from a broader geographic range will help capture the capacity for adaptation to a greater range of possible future climate scenarios (Puettmann 2011; Butler et al. 2012; Vilà-Cabrera et al. 2018). Relaxation of rules regarding the transfer of seed stocks should be considered in order to allow for enhancement of genetic diversity to occur (Gauthier et al. 2014).

1.1.3.3 Promoting Transition

Transition adaptation options represent an acceptance of inevitable change and deliberate guidance of that change in a direction which will produce a more desirable future state (Millar et al. 2007). Facilitation of this change through species and assemblage transitions will help to maintain the flow of ecosystem services in the face of a changing climate (Butler et al. 2012; Gauthier et al. 2014). Favoring and restoring native species predicted to fare better under climate change is one way to achieve this aim; however, transition can include establishment and encouragement of new mixes of native species for no-analog climate futures as well as management for species and genotypes with much wider environmental tolerances (Puettmann 2011; Butler et al. 2012). Transition can be facilitated through the protection of corridors as well as biodiversity hotspots with high evolutionary potential (Gauthier et al. 2014; Morelli et al. 2016), but this requires a large land base and high operational capacity. Otherwise, transition may need to be an active operational process.

Anticipating species declines will allow for better guidance of future stand composition (Butler et al. 2012). In general in Eastern North America, the rate of climate change will outpace tree species' ability to expand their ranges in response to changing conditions (Sittaro et al. 2017). Aitken et al. (2008) predict three possible outcomes under climate change: adaptation, migration, or extirpation. These factors, imply a need, at least to some extent, to guide the transition of ecosystems where a specific state or set of ecosystem services is desired (Iverson and McKenzie 2013). Climate suitable plantings, wherein species are selected from climate regions analogous to future conditions (Duveneck and Scheller 2015, 2016), can serve to transition ecosystems. Assisted migration was originally proposed as a means to preserve vulnerable species where changes in conditions have occurred or are occurring (assisted colonization) (McLachlan et al. 2007) but has more recently been viewed as a tool to preserve the continuity of forest cover and the flow of ecosystem services under climate change (Pedlar et al. 2012). In a forestry context, assisted migration can occur in a number of ways including: assisted population migration involving movement of species or provenances within their current ranges, assisted range expansion wherein species are moved just out of their current ranges, or assisted species migration where species are moved to areas of more suitable future climate (Williams and Dumroese 2013).

Current implementation of assisted migration is limited to those species and cultivars for which provenance data exists and transfer procedures are in place (Pedlar et al. 2011). Guidelines for the transfer of seed and plant material are also seen as a limitation within the current policy context (Williams and Dumroese 2013). Opponents argue that there is not currently enough data about the outcomes of assisted migration experiment and not enough is understood about the way introduced species will play into biotic interactions for it to be a viable conservation strategy (Ricciardi and Simberloff 2009; Bucharova 2017).

Similarly, acceptance and management of novel ecosystems (Hobbs et al. 2006) in conjunction with management for novel climates has been suggested in response to the conditions of a changing world. However, sustainably managing novel ecosystem components requires explicit consideration of values based judgements and the social aspects of natural resource management (Backstrom et al. 2018). Additionally, a spectrum should be recognized which spans from management under no-analog conditions to acceptance of novel assemblages to intentional creation of designed ecosystems (Higgs 2017).

Disturbance will play a major role in the state shifts of ecosystems associated with climate change. It will be essential to prepare to respond to more frequent, more severe disturbance driven changes in order to realign ecosystems following major perturbations (Butler et al. 2012; Janowiak et al. 2014b; Vilà-Cabrera et al. 2018). Prompt revegetation of sites following disturbance will help prevent further degradation and provide an opportunity to plant future adapted species assemblages that are tolerant of increased stressors (Wiensczyk et al. 2011; Butler et al. 2012; Gauthier et al. 2014; Duveneck and Scheller 2015, 2016). Active management of invasive species and early seral colonizers will be important in order to guide the transition of certain stands and prevent conversion to undesirable assemblages (Pidgen and Mallik 2013; Janowiak et al. 2014b).

1.1.3.4 Protection of Refugia

Viewed as both a method for resistance to climate change (Swanston et al. 2016) and promoting ecosystem resilience (Ogden and Innes 2007; Gauthier et al. 2014), another important component of adaptation cited in much of the literature is identification and protection of climate change refugia. Managing for climate refugia requires that the concept be defined operationally. Several definitions of refugia exist with varying scales and relevance to climate change adaptation. Morelli et al. (2016) defines climate refugia as areas relatively buffered from contemporary climate change over time that enable persistence of valued physical, ecological, and socio-cultural resources. Keppel et al. (2012) defines them as habitats that components of biodiversity retreat to, persist in and can potentially expand from under changing environmental conditions. The main theme behind the idea of refugia in a climate adaptation context is that they are areas that are relatively buffered from many of the negative effects of climate change in which some value can be preserved over time (Morelli et al. 2016; Swanston et al. 2016). These areas must be large enough to sustain some value of interest including species or populations which are at risk across the greater landscape. These areas generally have either a more favorable climate or greater availability of some limiting resource as a result of topography, underlying soil, greater moisture availability owing to a spring or stream, or some other feature which otherwise allows for the preservation of some threatened value. The ability to better buffer against disturbance than the surrounding landscape can also indicate refugia (Keppel et al. 2012). Creation or expansion of reserves serves to maintain representative forests and protect areas largely undisturbed by human activities (Gauthier et al. 2014; Duveneck and Scheller 2016). Refugia can also serve as unmanaged "controls" which can serve as study sites for comparison and evaluation of the efficacy of adaptation options.

1.1.4 Monitoring and Success Criteria

Determining the success of adaptation options will be difficult as climate change is an ongoing process rather than a discrete event. An iterative, ongoing process which allows for lessons to be learned and applied within an adaptive management framework will be critical for dealing with climate change (Millar et al. 2007). Monitoring to feed into adaptive management is called for in both the Climate Change Response Framework and the Canadian Council of Forest Ministers framework (Janowiak et al. 2014b; Edwards et al. 2015). The CCFM provides guidelines for updating criteria for the achievement of sustainable forest management in the context of climate change (Williamson and Edwards 2014). Beyond that little guidance is offered in any framework other than the monitoring that pertains to whether or not management goals were achieved.

The literature pertaining to successful climate change projects is limited as climate change is ongoing and other than in a modelling context it will be difficult to evaluate the efficacy of adaptation treatments for some decades to come. Some work has been done to look at ways to overcome barriers to implementation and how to make adaptation projects successful. For example, Ontl et al. (2018) reviews projects that implemented the CCRF and attempts to elucidate some of the regional and perception based decision-making factors. However, the authors acknowledge that true evaluation of CCRF projects and associated changes in attitude will occur over time. Halofsky et al. (2018) reviews US and Canadian adaptation frameworks, summarizing the state of knowledge and progress in implementation and suggests factors for success of implementation: 1) Good personal relationships, clear communication 2) Engagement of leadership and resource managers early on to establish ownership of the project 3) Embedment of research scientists within the process 4) Iterative shared learning.

Some examples of implementation of the various climate change adaptation frameworks exist. In the Yukon, regional scale climate adaptation was undertaken using the principles of the CCFM (Ogden and Innes 2008). Janowiak et al. (2014b) reviews two examples of implementation of the CCRF in the United States and Ontl et al. (2018) discusses the broad patterns of implementation; however, detail is limited at the level of the decision making process for components such as vulnerability assessment and selection of adaptation options in both. The updated CCRF Adaptation Workbook (Swanston et al. 2016) provides several examples of outcomes of application of the framework an expanded list of adaptation examples is available at adaptation.org. Adaptive Silviculture for Climate Change, an experiment to test the efficacy of adaptation options from the CCRF, is being carried out at several locations across the United States with treatments representing resistance, resilience, and transition being compared against a no-action control (Nagel et al. 2017). An example of implementation of the Adaptation Partners Framework exists in Southern Oregon which delineates how the framework was applied at each step (Halofsky et al. 2016).

2 Creating an Adaptation Focused Management Plan

2.1 Case Study – The Ford Forest

The Ford Forest is an approximately 5,000-acre collection of research forest properties owned by Michigan Technological University and managed by the School of Forest Resources and Environmental Science in the Upper Peninsula (UP) of Michigan and Northern Wisconsin. The largest portion of the property (approx. 3,700 acres) is located nine miles south of the town of L'Anse with the rest scattered throughout the western UP and northern Wisconsin in tracts ranging in size from sub-acre to 300+ acre holdings.

Administration of the Ford Forest is done by the Ford Center and Forest Director, an appointed faculty member within the School of Forest Resources and Environmental Science. The director is advised by The Ford Center and Forest advisory committee (hereafter "FCF Committee"), a group of faculty tasked with advising decision making surrounding the forest and its management. The FCF committee is made up of the school's forester as well as a group of faculty with different areas of expertise including: silviculture, forest ecology, geographic information systems, human dimensions of natural resources, and remote sensing. The FCF director and FCF Committee were responsible for decision-making surrounding the various components of this plan. This involvement is described in more detail below.

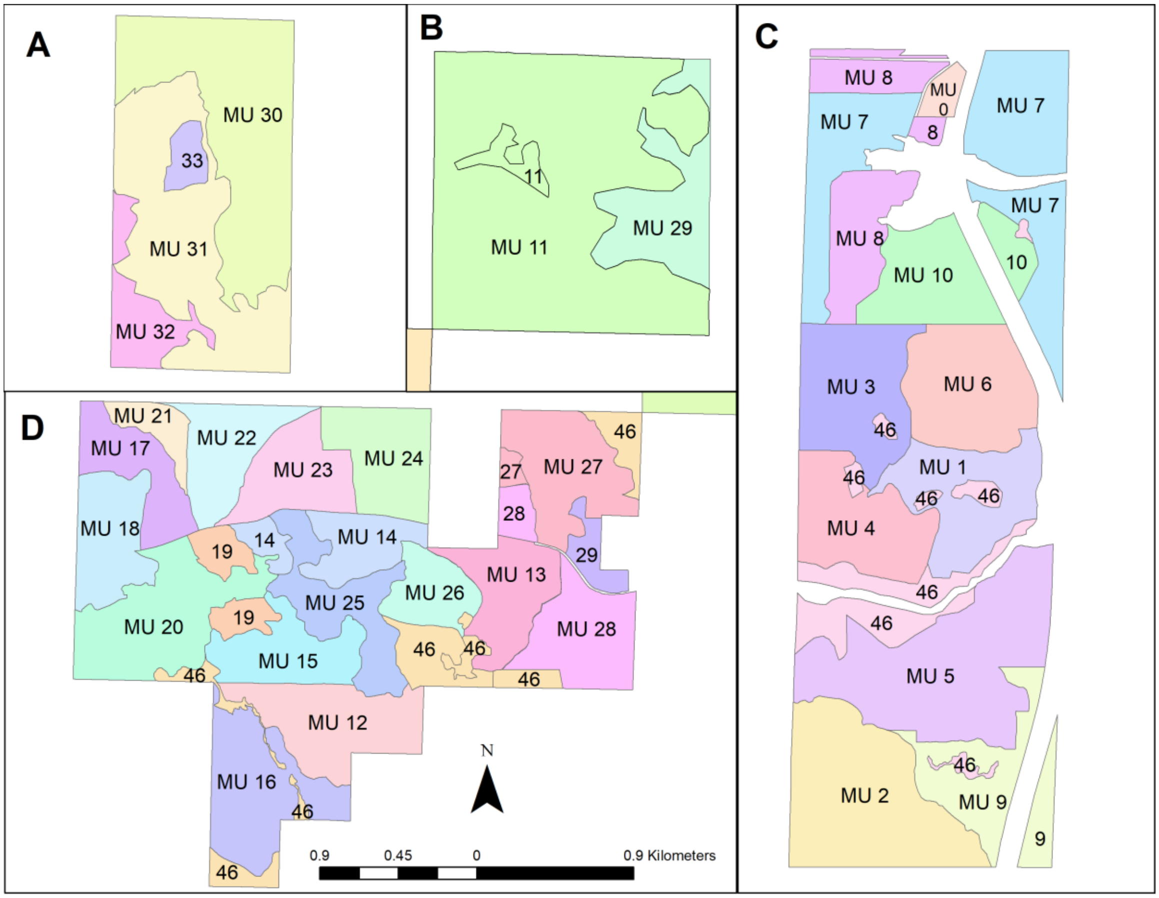

Figure 1: Management units comprising A) Section 2 B) Section 12 C) the Ford Lands Tract and D) the Baraga Plains Tract on the Ford Forest near the village of Alberta, MI

The large focal property, commonly referred to as the Ford Center is made up of two large tracts and two smaller partial sections (fig. 1). The easternmost tract, comprising roughly three sections is known as the Ford Lands and was donated to Michigan Technological University in 1954 by the Ford Motor Company. The large western tract, referred to as the Baraga plains was donated to the school by the Michigan Department of Natural resources in 1957 along with a separate but nearby half-section (referred to as section 2) and quarter-section (referred to as section 12) of forest land. Where practicable, the majority of the property is actively managed for revenue generation and research and education purposes. This exercise was focused primarily on these central tracts for the purpose of demonstrating and testing adaptation concepts. These lands are located centrally within the Laurentian Mixed Forest Province (Province 212; Bailey 1995), a transitional region between the boreal forests north of Lake Superior and broadleaf deciduous forests further south. Several tree species, such as jack pine and quaking aspen reach their maximum southern extent within this forest region, and therefore may be particularly susceptible to climate change (Duveneck et al. 2014).

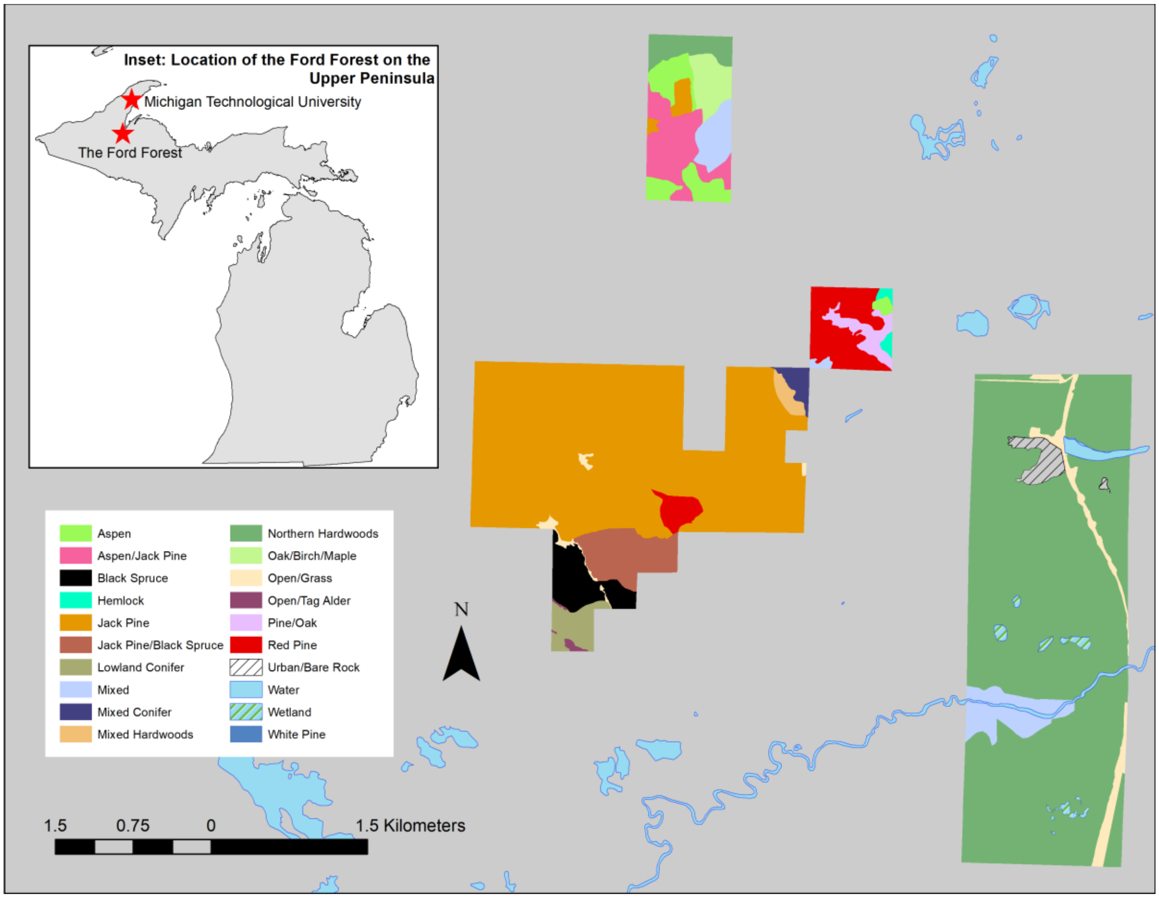

Figure 2: Cover types of the Ford Lands and Baraga Plains Tracts of the Ford Forest.

The Ford Lands are on a mix of generally mesic soils which supports a cover type of northern hardwoods heavily dominated by sugar maple (*Acer saccharum*). The Sturgeon river divides the bottom third of the tract from the main portion on which a mix of northern hardwoods and hemlock are dominant. The jack pine (*Pinus banksiana*) dominated plains are located almost entirely on a coarse sandy, glacial outwash with a portion of saturated black spruce (*Picea mariana*) swamp and pockets of red pine (*Pinus resinosa*). The separate, northernmost half-section, section 2, supports a mix of northern hardwoods, mixedwoods and pockets of pure jack pine. The nearby quarter-section, section 12, supports multiple stands of natural fire-origin red pine as well as northern hardwoods and pockets of northern red oak (*Quercas rubra*) dominance.

The forests of the Upper Peninsula, including the Ford Forest, have been influenced by human activity for millennia by Anishinaabek peoples who inhabited and still inhabit the area. Following settlement in the nineteenth and early twentieth centuries, management was focused on intense harvest of first softwood species, and then hardwoods as technological improvements made transport easier (Karamanski 1989). Prior to its donation to Michigan Tech, the Ford Lands were harvested intensely by the Ford Motor Company with about 75% of the volume removed (Bourdo and Johnson 1957). Since donation, management of the Ford Forest has been focused on research, education, and demonstration with timber revenues supporting these pursuits. A number of scientific studies are currently active on the land base.

Contemporary climate in the area is characteristic of the Northern Great Lakes region with Lake Superior being the primary driver of weather patterns. The lake effect dominates the climate in the region with solar energy and temperatures generally lower than further south in the region. Mean annual temperature for the region is 41.5° F. Mean annual precipitation is 32 inches with the majority falling during the growing season. An average of 160-220 inches of snow falls annually (Janowiak et al. 2014a). Of importance to note is the idea that these dynamics will likely be altered by climate change. Mean annual temperature for the region is predicted to increase between 2.6 ºF (1.5 ºC) and 8.7 ºF (4.8 ºC) by century's end. Precipitation in terms of average annual quantity is predicted to show little change or a slight increase, but total summer precipitation may decline sharply leading to an increase in drought conditions and possibly more extreme flood-like events. Critical to ecology and forest management is the prediction that ratios of evapotranspiration to precipitation may increase sharply under more severe climate change scenarios (Janowiak et al. 2014a; Melillo et al. 2014).

2.2 Integrating Adaptation into Forest Management Planning

In order to begin creating a climate change adaptation focused forest management plan we utilized the process laid out in the Climate Change Response Framework (Janowiak et al. 2014b; Swanston et al. 2016). We chose the CCRF process because of all the frameworks, it was designed to be most compatible with the size and decision-making context of our land base. The CCRF Adaptation workbook outlines a 5-step adaptive management approach which requires reevaluation and some level of adjustment at regular intervals based on the outcomes of past decisions. It begins with definition of the area of interest and creation of goals or objectives, then assessment of the ecosystem's vulnerability to predicted climate change followed by reevaluation of management goals based on these findings. Then adaptation options are compiled and selected after which implementation theoretically occurs. At this point, monitoring generates data used to evaluate the effectiveness of these adaptation options and actions are adjusted accordingly.

While the general pathway laid out by the CCRF was followed quite closely, we expanded upon certain steps and modified some processes. First and foremost, the CCRF process is designed to be incorporated towards achievement of previously established goals and objectives with climate as a filter. Here we have incorporated consideration of climate change into every level including definition of goals. Additionally, we expanded upon the vulnerability assessment process, demonstrating how other indices can be applied towards this end. Finally, we devised a novel means to evaluate the focus of a climate change adaptation driven management plan.

2.2.1 Defining the Area of Interest and Setting Goals

The area of interest for this exercise was already predefined: All forest properties owned and managed by Michigan Technological University's School of Forest Resources and Environmental Science. Here we focus particularly on the central Baraga Plains and Ford Lands tracts with some attention given to outlying properties. The planning process began with a comprehensive review on the status of all land holdings. Prior strategic planning efforts were also summarized and reviewed in order to set priorities for the planning process itself (see Management Planning History, appendix 1).

Our process varies from many of the demonstration projects that use the CCRF in that climate change adaptation planning occurred concurrently with a completely rewritten management plan rather than a separate adaptation plan. As such we sought to integrate climate change and climate adaptation into our goal setting process rather than adjusting our goals based on climate vulnerability. In order to achieve this a method known as backcasting (Sandström et al. 2016) was applied. The FCF Committee identified an ideal future for the forest and then worked to parse out the associated values that make up that outcome, creating a set of desired future conditions in the process. In this case "future" was defined as 80 years from the time of the exercise. The committee then worked backwards from this desired future in order to identify broad level adjustments that would be required to set the management trajectory on the necessary path.

2.2.2 Assessing Climate Risk and Vulnerability

Vulnerability assessment began with the calculation of Climate Risk Metric (CRM) (Janowiak et al. 2017) scores using inventory data collected from 1/20th acre permanent plots measured between 2010 and 2012. CRM scores were determined for each stand in the area of interest using importance values determined from relative frequency, relative density, and relative dominance calculations and binary determinations of climate driven habitat "gainers" and "losers" from the regional vulnerability assessment (Janowiak et al. 2014a). Risk metric scores were then mapped by stand using ESRI ArcGIS for visible interpretation. With the CRM mapped, a subset of the FCF Committee then assessed where they did and did not agree with ratings based on professional opinion and experience on the landscape. Disagreement was not based on any problem with the data or process, but rather where they believed underlying landscape elements (i.e. topography, soil, etc.) made the actual risk higher or lower. They then worked to interpret and assess the main drivers of the determined risk metric scores. Two main factors were found to be of primary importance to further vulnerability: drought and fire risk.

Drought risk was assessed using the drainage index (DI), a rating of the long term moisture holding capacity of a soil unit based on taxonomy, slope and aspect (Schaetzl et al. 2009). DI scores range from -1 (driest) to 100 (open water). For our purposes, soil moisture holding capacity was assumed to be analogous to buffering ability against drought risk as it indirectly represents the length of time that a soil unit will maintain moisture following cessation of precipitation. Higher scores are indicative of soils which are wetter over time where lower scores indicate dryer, typically sandier soils. DI scores generated by the USDA Forest Service were then mapped by NRCS soil unit using the mukey within the Michigan soil survey data (SSURGO format) layer. Property bounds were overlaid for improved visual interpretation.

Fire risk was assessed indirectly using the fire and fuels extension of the Forest Vegetation Simulator. Permanent inventory plot data was used to assess fire risk for a 10-year cycle from 2012-2022. To represent the actual risk of a fire spreading across the property and reaching catastrophic levels in terms of proportions destroyed, three metrics were chosen: the torching index, the crown index and the probability of torching. Each metric was rated by stand and mapped for visual interpretation.

Within a tract, the combination of the risk metric, the drainage index and the various fire risk metrics revealed some of the potential drivers of climate change vulnerability. A qualitative synthesis of the various metrics was performed to determine how the interplay between each driver might unfold under a changing climate. These possible dynamics were summarized and incorporated into the management plan as a combined summary of current conditions and potential risk factors. As the summaries were largely qualitative analyses of quantitative metrics, scaling the various levels of vulnerability would have been difficult and possibly inappropriate. Instead, tracts where multiple vulnerability metrics were rated high were assumed to be relatively more at-risk. The various, mapped vulnerability metrics were then presented to the full FCF Committee to inform management actions in response to potential climate risks.

2.2.3 Composing Achievable, Adaptation-Focused Objectives and Strategies

Essential to the creation of management objectives was the consideration of previously identified climate risks, use of climate change adaptation actions with some basis in the literature, and adherence to a proper planning hierarchy designed to be specific and achievable as well as provide for accountability. This was accomplished in a multi-step process. The first step involved collecting a range of adaptation options and strategies from across the body of climate change adaptation literature. The second step required selection and reconfiguration of adaptation options based on appropriateness to the predefined management goals as well as the land base and region. The final steps were an iterative process involving the amendment of objectives and strategies by the FCF Committee to contain both a measure of success and a time frame. Behind both elements was a desire to guarantee a climate focused plan as well as one in which time bound accountability would guarantee a greater likelihood of specific action being taken. Taking place concurrently with this process, management actions unrelated to climate adaptation were composed which sought to respond to the changes in strategic direction of the Ford Forest.

Compilation and selection of adaptation options involved a broad but selective review of climate change adaptation literature. The vast majority of options appropriate for the scale of operation that we were concerned with came from the CCRF (Swanston et al. 2016). However, given the universality of many aspects of forest management, useful methods could be found within other contexts. Adaptation options were drawn from a number of other frameworks including the Canadian Council of Forest Ministers Framework and many of the concepts on planning for increased disturbance laid out in Vilà-Cabrera et al. (2018). Many of the adaptation actions derived from the literature were designed to be broadly applicable and so a general lack of specificity had to be amended to make options relevant at the scale of our operations. An emerging body of literature on managing forests as complex adaptive systems was also drawn from for management options to increase the self-organizing abilities of stands in the face of global change (Puettmann et al. 2009; Puettmann 2011). From the compilation of many options a list of potential approaches was composed.

From a list of potential adaptation options and consideration of overarching management goals, a series of draft management objectives were created which aimed to respond to climate risks as well as strategic changes in the management of the Ford Forest. Because this was a complete reevaluation of management on the Ford Forest not all of objectives pertained to climate adaptation. This list was evaluated, amended and agreed upon by the FCF Committee. The committee removed or amended objectives deemed inappropriate, unachievable, or impossible to measure with the exception of a few deemed aspirational which were maintained to help guide the strategic direction of management planning in the long term. Then, to promote accountability and action, the committee sought to make objectives specific, measurable, achievable, and time bound (SMART) (Long et al. 2010). Desirable objectives were evaluated to determine a metric of success and a time-frame for their achievement.

Following this step, strategies were composed to reflect more specific, discrete actions and parameters in support of specific objectives with the same time-frames and metrics of success. These strategies were then presented to the FCF Committee in a separate meeting months later, amended and approved. Both objectives and strategies were designed to adhere to a planning hierarchy in which each component corresponded to one above. The entire planning process unfolded in an iterative fashion. At each stage of planning, the various hierarchical components were reconsidered and amended to promote agreement among the various levels of the plan. At the end of this process a unified document containing Forest management goals, objectives and strategies as well as time frames and metrics of success was agreed upon as a complete document.

2.2.4 Evaluation – Distinguishing Business as Usual from Climate Adaptation

Management is a science and there are lessons from management science that can be applied to understand and improve management planning in our context. For example, there are sometimes thought to be different models of decisions making: rational, semirational, and “garbage-can” (Boston and Bettinger 2001). Truly rational decision-making based on complete information and thorough processes is typically quite rare, particularly in natural resource management. Semirational decision-making in which management alternatives are selected based on the best available information attainable given resource and time limitations is more common (Bettinger et al. 2017). Group decision making involving variability in expertise, experience and time devoted among team members as well as time constraints imposed by overseeing entities is characteristic of public and education-focused natural resource management organizations (Boston and Bettinger 2001). These components often push decision-making towards what is known as the garbage-can model (Cohen et al. 1972). This model occurs when goals and objectives are unclear or problematic, the technology or process to achieve objectives is unclear or poorly understood, or the involvement of team members is variable based on available time and willingness. While not inherently problematic, this type of planning process often involves conflicting, values-laden management decisions that require amendment over time.

Decision making in public and education-based natural resource management organizations often involves higher-level mandates beyond economic or profit-driven considerations. This means that decisions made by these types of organizations also have a greater range of consequences that must be considered including political, social, and ecological. Novel management actions constitute alternatives with largely unknown consequences, making them higher risk (Gezelius and Refsgaard 2007). To manage risk, the planning process often involves the application of tried and true solutions to problems where such action is still appropriate. This impacts the way new management alternatives are composed leading to proposed actions resembling previously applied and tested solutions and limiting the degree of novelty (Gezelius and Refsgaard 2007). Aversion to novelty within organizations can be problematic given the novel and no-analog climate conditions for which responses are needed. Climate adaptation involves novel application of traditional management as well as novel, untested solutions. This new context requires that decision-making balance the necessary novelty with an aversion to radical solutions centered on risk management.

The decision-making surrounding management of the Ford Forest can be characterized as having been semirational and bordering on the garbage-can model. Organizational and individual time constraints required decision making that was based on and accounted for limited information. Value based judgements and skepticism of more radical management actions were limited but still impacted plan outcomes. For example, the FCF Committee identified as an important objective the protection of unique sites. While “unique” is a poorly defined descriptor, a number of sites were already in mind for certain committee members. None of these sites were identified based on any attribute contributing to landscape adaptability or ecosystem services. Instead a vague interest in their uniqueness and potential educational value resulted in their protection. Additionally, administrative changes within the overarching school lead to changes in the size and composition of the FCF Committee between the goal setting and vulnerability assessment steps. Cycling through an iterative process with frequent involvement of the planning committee allowed for the creation of a plan that was largely satisfactory to, or at least unobjected by, its framers.

However, one primary consideration with adaptive management is that evaluation of the efficacy of management actions takes time. Where the context of climate change is added, the time scale can be even more severe as the efficacy of some actions will only become clear following both implementation and ongoing shifts in climate norms. As such, it becomes necessary to evaluate whether or not the actions being taken will actually have an impact from the standpoint of climate change adaptation. While the actual stability of the system will only become clear over time, the plan itself can be evaluated for the novelty and intent of proposed actions. As the plan was intended to be comprehensive with a climate focus, it was important to evaluate the extent to which specific actions were focused on climate change adaptation versus business as usual or something analogous to such.

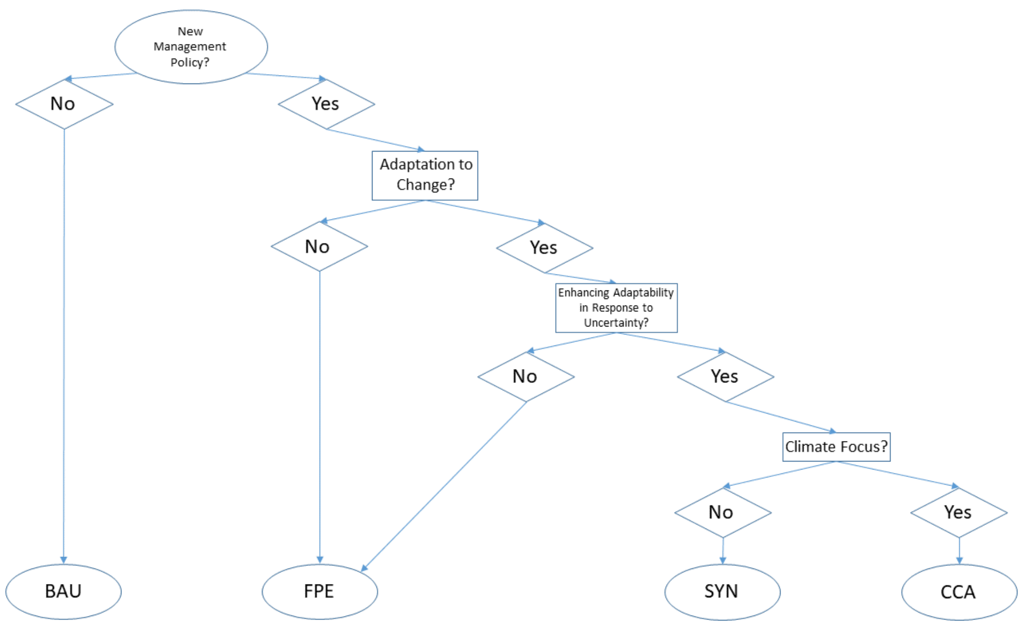

Figure 3: A flowchart for the categorization of management actions. Business as Usual (BAU), Forest Protection and Enhancement (FPE), Climate Change Adaptation (CCA), and Synergistic Actions (SYN) are represented.

Here, we propose a method for evaluating management plans for climate focus as a means to account for semirational or garbage can decision making and the potential novelty-aversion inherent in many public organizations. To do this, management actions are sorted into four categories along a spectrum based on the extent to which they relate to climate adaptation. The two ends of the spectrum are business as usual (BAU) and climate change adaptation (CCA). For the purposes of this analytical step BAU refers to any management action which has either been previously applied or is focused on general operational attributes and not any kind of adaptability or response to change. CCA is made up of those actions specifically focused on adaptability or the ability of a system to maintain ecological function in the face of climate change. A third category, Forest Protection and Enhancement (FPE), represents those actions which seek to improve or protect certain attributes of the forest but not necessarily promote the resilience or adaptability of the system or factor in climate variability and future trajectories. These policies fail to take complexity, uncertainty, and emergent properties into account but may still indirectly improve resistance and resilience to global change. A final category, synergistic actions (SYN), captures those actions which are not explicitly targeted at climate response, but still serve to promote resilience or adaptability of the system to change. SYN actions may have been previously applied or otherwise completely novel. Theoretically, a comprehensive, adaptation focused management plan should have a mix of CCA and SYN actions as well as some BAU and FPE policies. As this process is somewhat subjective, it should not be viewed as a scoring or grading policy, but rather an additional step to ensure that consideration of climate change vulnerability and adaptation options has been translated into planned actions corresponding to identified vulnerabilities and organizational priorities. Following final agreement of the goals, objectives and strategies, an independent assessment was performed on the objectives and strategies sorting each action item into these categories.

3 Outcomes of the Planning Process

3.1 Goals and Desired Future Conditions

Major themes of the DFC’s are highlighted here. In both the DFC’s and specific goals, a limited focus on climate change is reflected. Instead, both were focused on the broad values which were sought to be preserved with climate change viewed as more of filter or an obstacle. Much emphasis was placed on the continued existence and growth of the Ford Forest. Program visibility and continuity was seen as important with specific focus on research, institutional partnerships and community engagement. Forest management aims focused on constant pursuit of cutting-edge techniques within a management plan designed with a clear planning hierarchy. Continuity of timber value was also seen as important. Threats from invasive species and catastrophic fire were specifically identified as possibly being exacerbated by climate change and, more broadly, global change. Changes in species suitability resultant from climatic shifts were also recognized as major threats requiring incorporation into the management plan. Finally, traditional ecological knowledge, maintaining a historic range of ecological processes and conditions, adaptive management, the full spectrum of ecosystem services and consideration for existence value were all identified as critical values requiring attention within the plan.

A series of management goals were drafted corresponding to the values identified as part of the backcasting process. Initially, 10 goals were composed which were eventually reduced to eight which best reflected DFC’s achievable through forest management. These included:

1. Public and professional recognition of Ford Center and Forest as a teaching, research and demonstration forest including novel forest treatments. Links to the strategic plan with an aim to achieve goodwill amongst surrounding communities and partnership with other institutions and landowners for replication of novel treatments and greater engagement
2. Managed ecosystems with successful regeneration and compositional diversity that set the standard for resilience goals in the region
3. Managed stands representative of a variety of ecosystems with varying forest types and successional stages as well as a variety of forest treatments across the land base
4. Fire managed on the landscape as a major driver of forest types
5. Invasive species and severe, climate change driven outbreaks of endemic pests anticipated, managed for, and controlled
6. Protect productivity of terrestrial, riparian, and aquatic ecosystems and associated ecosystem services in light of anticipated climate change and resulting impacts
7. Creation of an adaptive forest management plan designed to demonstrate the management process, feature ecosystem services, and allow for adaptation of forest resources to global change

8. Sustained output of timber sufficient to finance state-of-the-art forest management activities and research

3.2 Vulnerability

Ecosystem vulnerability varied across the property based on factors including topography and underlying soil. Within the northern hardwoods stands of the Ford Lands tract vulnerability was driven by dominance of vulnerable species as predicted by the regional assessment and a general lack of species diversity making for an assumed reduction in buffering capacity. Areas to the north of the property where different forest types had been pushed to sugar maple production created zones of already limited productivity with the potential for exacerbation under climate change. Large soil complexes with lower DI scores exist in patches within hardwood stands of the Ford Lands and are assumed to be much more susceptible to drought conditions during years of low or infrequent precipitation. Some of the northern hardwoods stands on drier soils are believed to have been pushed to maple dominance from more drought tolerant forest types under periods of more intense management for timber production. In these cases, vulnerability is a function of site suitability. Low lying areas of generally wetter soils exist near the center of the tract which may constitute climate refugia depending on the level of buffering created by the surrounding topography and long-term moisture availability. However, these areas are also dominated by species slated to decline as a result of climate change according to the regional vulnerability assessment (Janowiak et al. 2014a) and so their resilience will be dependent on the longevity of aforementioned underlying resilience factors. Other concerns such as invasive species and the potential frost damage from inconsistent winter snowpack (Cleavitt et al. 2008; Auclair et al. 2010) remain considerations which are less easily predicted but still require a planning response.

Within the dryer, more conifer-dominated Baraga Plains tract, fire was a major theme underscoring vulnerability. These systems are largely dominated by fire-adapted species including jack pine, red pine, and black spruce. Past management has created a mosaic of adjacent stands of mismatched ages resulting in the presence of ladder fuels which could create conditions which promote the movement of large fires across the property given the right conditions. FFE outputs can only predict how a fire would behave within a given stand but crown index, torching index, and torching probability demonstrate how a fire might be able to move across the tract depending on its site of ignition and prevailing wind conditions. With climate change increasing the occurrence and length of fire-weather like conditions, the risk of ignition and spread can be predicted to increase. Given the historical prevalence of fire within the region in pine-dominated systems (Karamanski 1989; Drobyshev et al. 2008; Nyamai et al. 2014) it can be assumed that warmer, drier conditions will increase the risk of catastrophic disturbance.

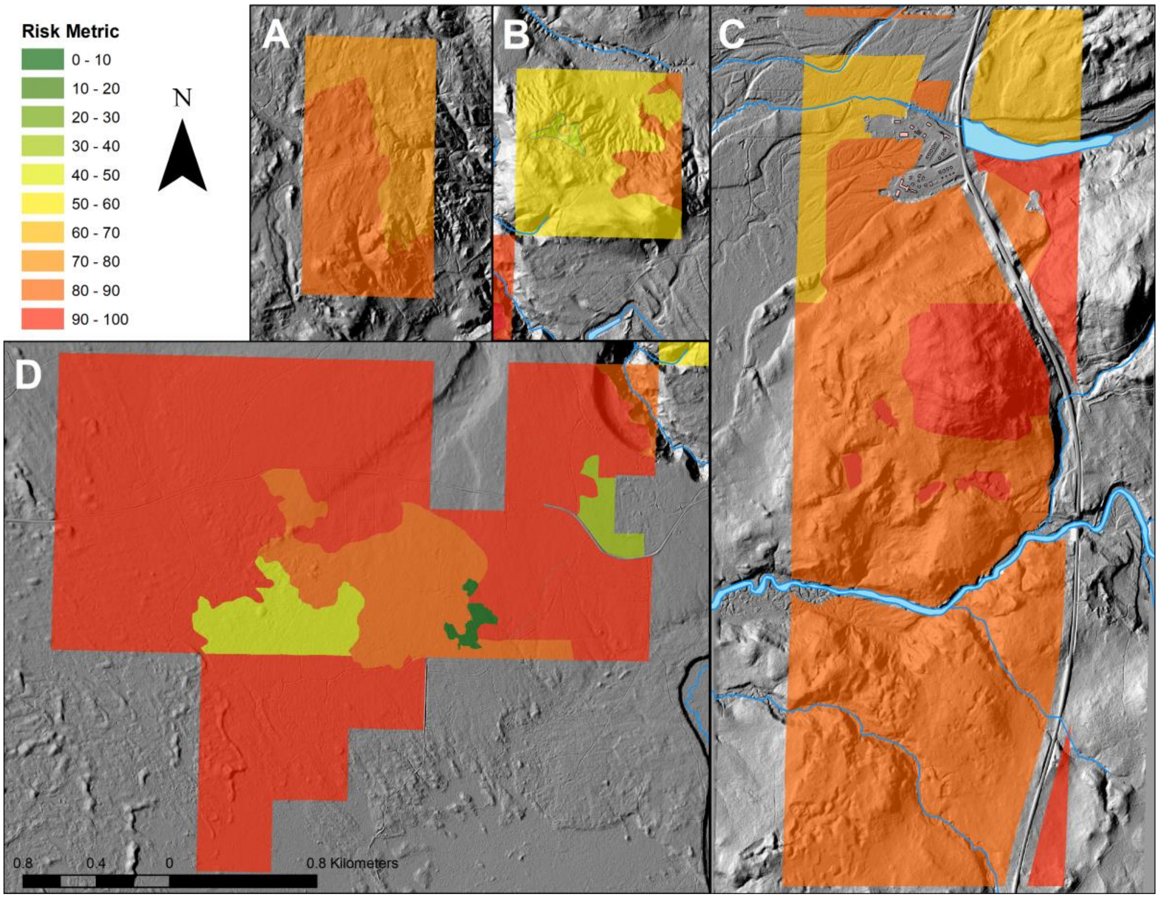

Figure 4: Climate Risk Metric Scores, by stand, for A) Section 2 B) Section 12 C) the Ford Lands Tract and D) the Baraga Plains Tract at the Ford Forest near the village of Alberta, MI.

Drought risk was also perceived to be quite high on the Baraga Plains, particularly because of a very large underlying complex of dry, sandy soil with very low DI scores (typically <20). In a system already dominated by the most drought tolerant species of the region on a soil complex that is already typically quite dry, a reduction in moisture availability may pose a threat as well as increase the risk of ignition. A high water table on the south end of this section may ameliorate some drought concerns but this will be dependent on the ability of the local provenance of jack pine to access this resource. Jack pine of a less suitable provenance to the region are also present on a portion of the property and constitute a section of potential vulnerability to loss of suitability. Areas of regeneration failure resulting from past management decisions are also present which may represent a potential liability.

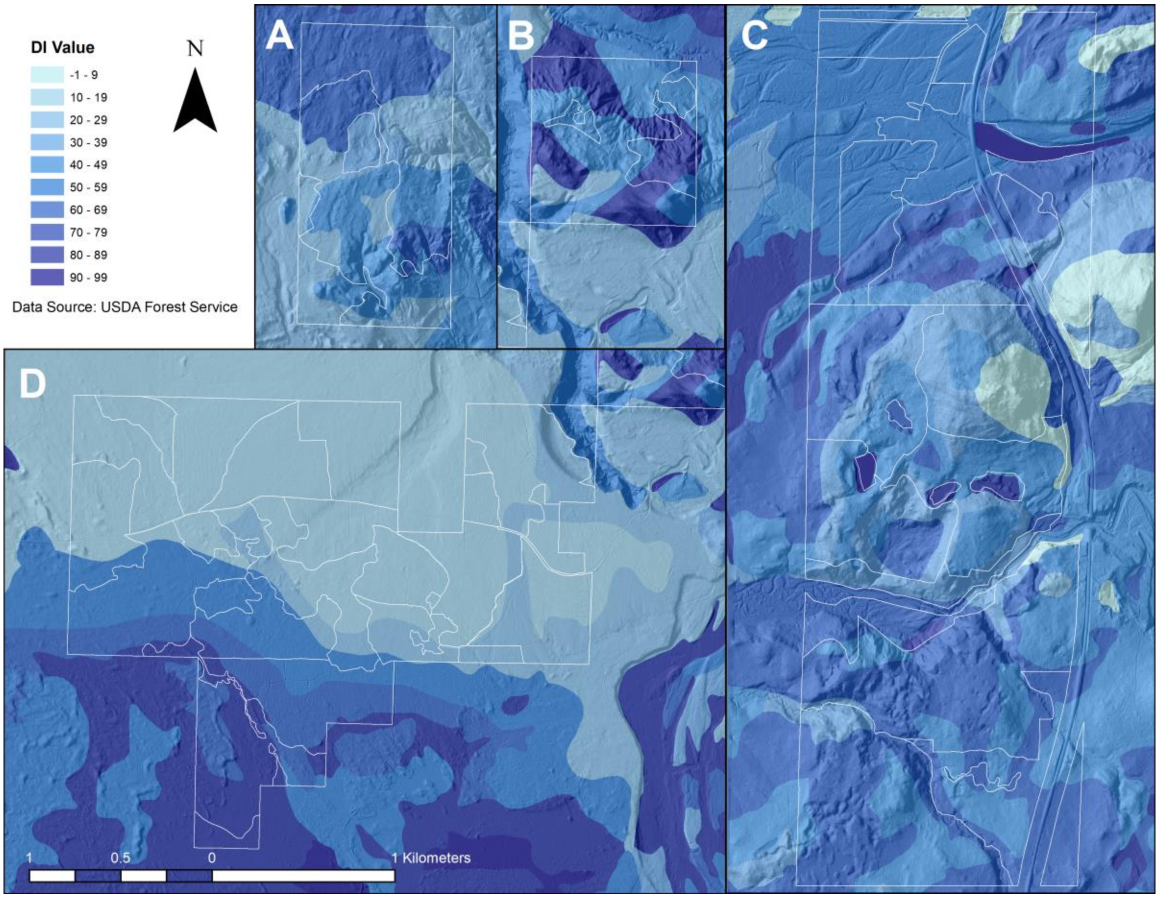

Figure 5: Drainage index scores for the soil units of A) Section 2 B) Section 12 C) the Ford Lands Tract and D) the Baraga Plains Tract at the Ford Forest near the village of Alberta, MI. Stand boundaries are overlaid in white.

In the smaller, disconnected sections (Section 2, Section 12) many of the species were coded as "at-risk" leading to higher CRM scores, but the relatively high species diversity and the somewhat higher DI scores of the underlying soils may serve to increase resilience. Additionally, the greater diversity of cover types may promote a greater level of resilience within these two sections. Across the land base, insects and disease as well as and including invasive species remain a major concern which may be enhanced by climate change.

3.3 Adaptation Actions – Objectives and Strategies

We identified a number of broad programmatic areas on the confluence of need in response to climate driven risks identified in the vulnerability assessment and practicability in terms of forest and natural resource management. These areas, along with other themes aimed at a refocusing of strategic direction for the Ford Forest make up the action items of our plan. Here we focus on those actions aimed at addressing and adapting to climate impacts. Table 1 provides a list of example objectives and strategies for adaptation to climate change. A few FPE actions are included here as they reflect a desire for resistance to stressors in response to climate change which we argue may or may not actually constitute climate adaptation depending on the intent of their inclusion. At the objective level we focused on: site suitability, fire resistance and resilience, species and structural diversity, natural drivers of ecosystems, moisture availability and stress, detection and management of invasive species, continuity of ecosystem function, establishment of climate refugia, and monitoring in support of adaptive management. At the strategic level, more specific actions and guidelines supported these broad areas.

Monitoring, enhancing and maintaining the suitability of tree cover at a specific site is a major theme in our plan. This is included in response to the potential for broad changes in suitability associated with climate change, but also in response to areas identified in the vulnerability assessment as having limited regeneration and higher potential for drought owing to underlying soils. Lack of advance regeneration and regeneration failures following disturbance or harvest will be major signals for adaptation action. We composed strategies which seek to enhance site suitability where it has already been lost due to past management regimes or to maintain or reestablish the resilience of cover on a site following degradation from climatic shifts. Such actions include both structural and compositional changes which could either affect a portion of a stand or, in more extreme cases, alter the composition of the stand entirely. Following adjustments, management based on silvicultural guidelines will be employed with an aim at maintaining forest health over time.

Table 1: Adaptation options at the objective level along with categorizations and example strategies. Included here are climate adaptation objectives as well as objectives which serve towards greater resistance and resilience to climate change.

Adaptation Objective	**Category**	**Example Strategies**
Manage northern hardwood stands for increased tree species diversity and response to changing site suitability.	CCA	Employ variable retention harvesting and underplant marginal sugar maple dominated stands with limited or unsuccessful regeneration.
Manage for drought and climate resilience in stand structure and composition. Avoid loss of stand complexity.	CCA	Protect the regeneration layer (from excessive herbivory, machine damage, etc.) and quickly revegetate areas that experience regeneration failure or dieback
Alter forest structure in pine-dominated systems to prevent increasing severity, spread of wildfires.	SYN	Perform or contract out analysis for the generation of a report and/or plan
Experiment with assisted migration and hybrid species to find suitable replacements for species or provenances which may be extirpated by climate change.	CCA	Utilize regeneration failures to establish trials of species with potentially expanded habitat and/or drought and climate resistant hybrid species. Use ornamental trees around research, teaching infrastructure as informal

		provenance trial and seed source for assisted migration
Maintain forest cover across time by managing for successful regeneration following disturbance	SYN	Appropriate stocking based on forest type using silvicultural guidelines for desired species. Plant where appropriate stocking rates are not met within 5 years
Maintain a diversity of age classes and successional stages across all forest types with increased structural heterogeneity and species diversity across the landscape.	SYN	In cover types where even aged management is appropriate, avoid uneven aged treatments, focus on retention within even aged systems In hardwood stands integrate different seral stages via patch or group selection combined with understory management (scarification, regeneration protection and management, planting)
Manage for landscape heterogeneity and complexity.	SYN	Advocacy/participation within networks of regional and local managers
Identify and establish climate refugia.	CCA	Identify, delineate, and define areas
Fire recognized as an inevitable and integral disturbance in ecosystems on a portion of the forest.	SYN	Prescriptions for stands in areas where fire is a major driver consider fire as a management option. Where fire is deemed unfeasible, prescriptions rationalize how fire effects are mimicked
Guide recovery following fire to prevent ecosystem conversion to non-forested systems.	SYN/ CCA	Promptly following disturbance determine if recovery or transition is desired. Prescribe action to achieve appropriate stocking of desired cover type.
Manage for tree vigor and resistance to insect and pathogen attack.	FPE	Focus on stands of known at risk species including: eastern hemlock, red pine and white pine. Manage to B-line of stocking charts
Respond strategically to invasive species detection to quickly control and/or mitigate potentially damaging invasions.	FPE	Develop and deploy educational materials to facilitate detection by recreational users, students and create a vector for reporting detection
Prioritize management of riparian areas and features to maintain function.	SYN	Map riparian zones and incorporated into prescriptions
Protect forest soils from disturbances related to forest operations	FPE/ SYN	Mitigation of compaction and soil rutting during all forest operations where soil impacts are possible

Manage for diverse site conditions and legacy elements to promote structural and compositional diversity	SYN/ CCA	Maintain legacy structural elements following harvest. Retain patches of down and standing dead wood as well as some mature live trees in stands following harvest
Incorporate monitoring towards adaptive management. Base forest management decision on the outcomes of previous management activities as determined by regular monitoring with a 5-year interval.	BAU/ SYN/ CCA	Completion of management plan revisions based on success/failures from previous intervals

A focus on species and structural diversity with an aim towards enhancing response diversity and the self-organizational capacity of the major systems within the forest is another major theme in our plan. While it should be noted that diversity does not equate to resilience, enhancing species diversity where possible and with strategic intent can still serve to increase the response diversity (Elmqvist et al. 2003) of a system. On the Ford Forest many areas of limited diversity exist including jack pine monocultures and northern hardwoods stands dominated by sugar maple. We prescribed actions aimed at increasing the compositional diversity of these stands in order to enhance the ability of the stand to transition in response to environmental change through an increase in the response diversity and self-organizational capacity of the system. Where species diversity may be more limited by underlying soil conditions, as in the jack pine dominated Baraga Plains, greater emphasis was placed on resilience. Enhancing structural diversity within stands was prescribed as a means to enhance response diversity through inclusion of different age classes and greater variability of site conditions as insurance against a range of possible disturbance regimes. Actions to improve structural diversity included: retention of down dead and standing wood as well as mature trees and sections of old growth. Efforts to enhance structural diversity at the forest-scale were also viewed as important and involved planning for a mix of stand-development stages across management units. The intent behind all diversification efforts was to enhance complexity both at the stand and forest level.

Within the plan we focused on fire categorically both in terms of potential damage from disturbance and also as a major driver of pine dominated systems of which a large portion of the property is composed. Improving fire resistance through fuels treatments and fire breaks was emphasized, though the FCF Committee eventually settled on a need for further analysis in support of such an end and worked this into the plan. Recognition of fire as a major driver was seen as essential by the FCF Committee in maintaining certain forest types including jack and red pine. Actions in pursuit of fire resilience including alterations to fuel dynamics and reintroduction of fire were considered and included to some degree in the management plan, but again the committee determined that further analysis was needed and this was prescribed instead. We included planned replanting following fire and subsequent regeneration failures as a way to either maintain resilience or take advantage of disturbance to transition poorly adapted systems.

Both planning for fire resistance and resilience were viewed as critical in light of the predicted increases in drought conditions and fire-weather annually (Melillo et al. 2014) and the less fire resistant forest structure revealed by the vulnerability assessment. Planning for fire as a component of jack and red pine dominated systems was seen as both a matter of resisting disturbance and maintaining specific forest types.

Consideration of the interaction of underlying soils and climate as major drivers of ecosystems was identified as a cause of potential drought stress during the vulnerability assessment step. To account for this, we prescribed action aimed at increasing the presence of drought and more heat tolerant species and provenances on sites with low DI scores indicating drought prone soils. Actions to improve drought tolerance include both planting of local, drought-tolerant species as well as planning for assisted migration. Candidates for species transitions include locally adapted red oaks, white pines, and future adapted northern and central hardwood species not currently occurring on the forest. Both in relation to fire and drought and climate tolerance, preventing undue transitions to non-forested systems was listed as an objective.

A few other programmatic areas were incorporated into the plan for the purpose of climate adaptation and response. Improving detection efforts and strategic response to invasive species was listed. Particular emphasis was placed on preserving or restoring ecosystem function in support of ecosystem services. This included delineation and protection of riparian areas, consideration of best management practices, promotion of diverse site conditions to promote complexity and compositional diversity, and maintenance of continuous and suitable forest cover. Finally, towards the end of climate adaptation, much focus was placed on regular inventory and monitoring in support of adaptive management. As adaptive management is critical in the context of planning for uncertainty, monitoring to inform such a system is essential.

3.4 Evaluation of Management Policies

Evaluation of our planned management actions revealed a plan that is fairly well distributed between the various categories listed above. At the objective level, management actions were nearly evenly split between the business as usual and the adaptation categories. The BAU and FPE categories were represented in about 30% and 22% of the objectives respectively. About 30% of the objectives were sorted into the SYN category and 18% were listed as CCA. At the strategic level it was more difficult to distinguish between SYN and CCA. Instead actions for either were viewed as interchangeable within a SYN/CCA adaptation to global change category. BAU actions made up about 38% of strategies, FPE made up 13%, and SYN/CCA made up 49% of strategies. At both the objective and strategic level, actions were almost evenly split between business as usual and non-adaptation focused objectives and those which sought adaptation to climate change.

A few things should be noted about this step of our assessment of the management plan. As previously stated, this should not be viewed as a score of our plan, it simply serves to demonstrate the level to which climate change and promotion of adaptability are a primary focus. Additionally, it allows us to evaluate whether or not the proportions of actions in each category correspond to the level of vulnerability and our organizational priorities. Actions have been sorted into the category where they best fit. In some cases, this has involved evaluating the intent of the action rather than what is explicitly stated in the wording and making logical assumptions based on the categorization of the associated objective or goal. Distinctions between SYN and CCA items were generally based on whether or not the essence of the prescribed action would be considered in the absence of climate change. FPE items may have contributed to climate response, but not necessarily to forward thinking adaptation. In some cases, multiple categories were applied as the emphasis on a BAU action was greater with climate change considered, as was the case with monitoring.

4 Discussion

4.1 Lessons Learned Through Application

In engaging in a complete rewriting of our forest management policies, we had the unique opportunity to consider climate adaptation within all aspects of forest management planning for our land base. In doing so we were able to integrate methods and tools at various stages of the planning process that had not been considered previously in this context. Additionally, this allowed us to reconsider the manner in which objectives and strategies were crafted in order to best ensure that adaptation techniques went beyond consideration to action. Listed here are some of the lessons learned through carrying out this process.

4.1.1 DFC's for an Uncertain Future

As previously stated, there is a schism in the literature as to whether climate adaptation is goal unto itself or a means to an end. In reality, and particularly for operational purposes, the answer is likely both. Even within frameworks where protection of biodiversity is the implied goal (Schmitz et al. 2015) it must still be stated as a value which is desired to be protected. Without identification of specific values, the best course of action for climate adaptation could be argued to be no-action to allow ecosystems to self-organize over time to a state that is suited to the new contemporary climate. Climate change adaptation requires explicit consideration of what values are being adapted. This involves consideration for resistance or resilience "of what to what" (Puettmann 2011) with the "to what" being the uncertainty and variability associated with climate and other global change.

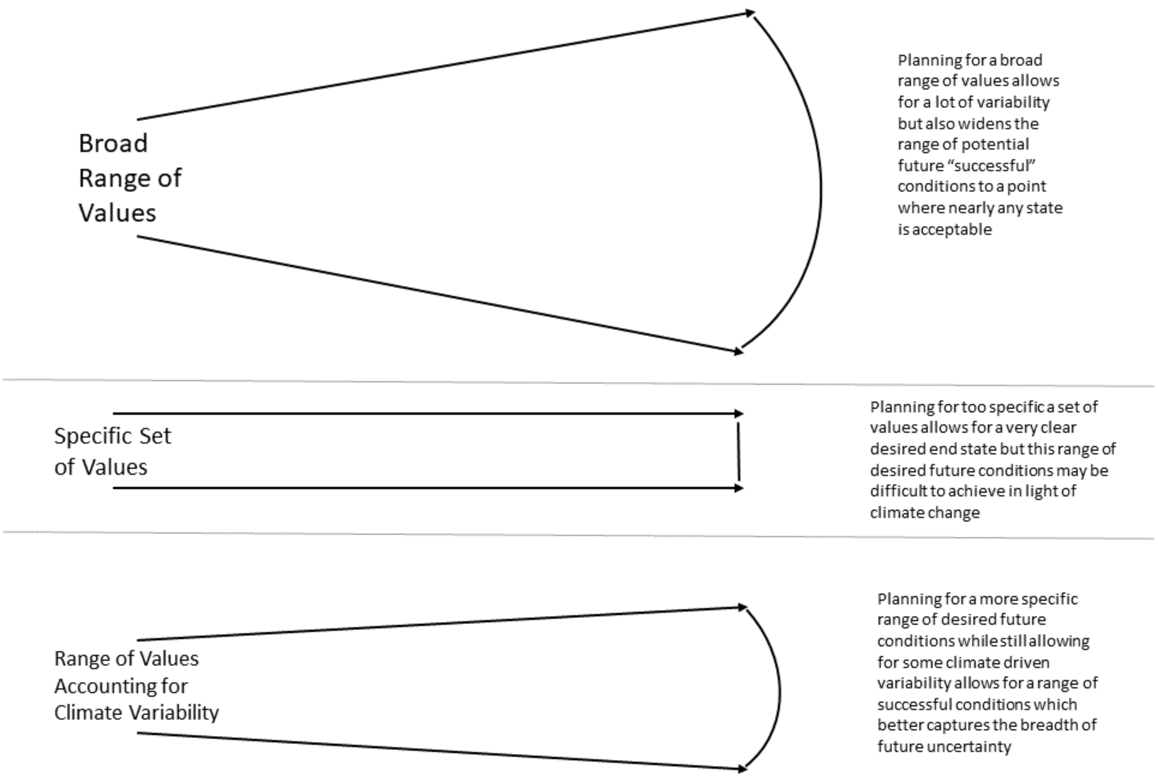

Figure 6: Demonstration of how identification of priority values affects planning outcomes.

Backcasting (Sandström et al. 2016) allowed for determination of critical values from the beginning of the planning process within the context of climate adaptation. By incorporating this method into our process we were able to both consider what values were critical as well as how these competing values might be ranked in terms of both importance and difficulty of preservation. This method also aided in drawing tangible values from more nebulous concepts, effectively creating a range of values from which to work when composing objectives.

The degree of tangibility of identified values came to be an important consideration later in the planning process. Cohen et al. (1972) points out that decision-making under the garbage-can model often involves working with goals and objectives that are less structured or nebulous. Awareness of this condition within our organization was necessary for guiding targeted action. Where it was difficult to identify a physical attribute associated with a value, it was difficult to choose or compose targeted actions. For example, a goal within the management plan was listed as "Fire managed on the landscape as a major driver of forest types". One interpretation of this goal posited fire as the value of interest here and the associated actions attempted to account for a vague interest in requiring fire to be utilized as a management tool. Clarification from the committee revealed that ecosystems where fire was a major driver were the priority value and that management simply needed to approximate fire effects in order to preserve this landscape component. Consideration of prescribed fire became a strategy instead of explicit requirement of its use. The more specific the value of interest, the better prescriptions can be written towards its preservation. Less tangible values allow for a broader range of success metrics but obscure the “of what” or the associated values for which protections are sought. While this may be appropriate for aspirational goals or low priority items, it vastly increases the difficulty of targeting actions and decreases the impact of ultimate intervention outcomes as it widens the range of “successful” outcomes. Conversely, prioritizing too specific of a range of values may narrow the range of successful outcomes to the point where their achievability becomes extremely limited or impossible in light of an uncertain climate future. Planning for specific values but allowing for some variability allows for composition of and management towards realistic targets in light of an uncertain climate future.

4.1.2 Making Regional Vulnerability Relevant at Local Scales

Predictions of the forest ecosystem effects of regional climate change provide a useful starting point for framing the problem of climate vulnerability at a local scale. However, predicting how climate dynamics and associated ecological effects will play out in a given location can be difficult or near impossible in a modelling context. Vulnerability assessments are most useful if they inform targeted actions or further analysis of climate risk. Here, the Climate Risk Metric assisted in the identification of the drivers of climate impacts on the land base and allowed for the use of the FFE and DI to further examine these dynamics. Critical to this analysis was consideration for timeliness and organizational capacity and reliability of the different forest models at various scales.

The progressively negative effects of climate change imply a need for urgency in taking action in preparation for associated ecological impacts (Janowiak et al. 2014b; Melillo et al. 2014). An argument can be made for vulnerability and risk analyses which are relatively inexpensive and provide information fairly rapidly within the time frame of a forest planning process. Or at the very least for provision of expedient information balanced against the need for information at a resolution relevant to forest management at the stand scale. Methods exist for using remote sensing assessments to determine drought dynamics at fine scales based on NDVI (Andrew and Warrener 2017). While such assessments would provide very fine-scale and spatially explicit information, they would likely be potentially expensive and time consuming. Here we favored the best possible information for informing decision making which was currently or could be made quickly available. Both the Climate Risk Metric and the various metrics from the Fire and Fuels Extension could be generated relatively quickly from previously acquired inventory data. Drainage Index scores were available as a premade data product.

The Climate Risk Metric was most useful in that it informed a discussion around the primary drivers of potential climate vulnerability, allowing for identification of the potential mechanisms of species decline on our land base. To that end, the Drainage index and Fire and Fuels Extension were only useful in the context of vulnerability assessment so far as they informed the extent to which two previously identified risks, drought and fire, might represent a vulnerability on the landscape. The DI and the various FFE metrics were able to elucidate the spatial dynamics of key risks and to allow for grouping of stands into areas of different vulnerabilities to inform prescriptions. The key in our vulnerability assessment was not to test for a comprehensive range of potential risks but to find metrics that best demonstrated the extent and spatial dynamics of previously identified risks.

Some limitations were inherent in our methods for vulnerability analysis. The Climate Risk Metric offers a view into the effects of a range of possible future climates. We calculated CRM scores based on the most severe climate future in order to capture the greatest level of risk. Climate outcomes may be less or more severe or may play out in completely different ways than what current models have identified. Our emphasis on increased drought and fire risk is based on a future in which dryer summers with less frequent precipitation events occur (Janowiak et al. 2014a; Melillo et al. 2014) but precipitation is notably difficult to predict accurately, particularly at regional and local scales, so the range of future issues may be much different. To respond to this, we have sought adaptation actions that attempt to increase the adaptability or self-organizational capacity of forests rather than the ability to persist under specific climate outcomes. Other limitations included the ability to capture spatial variability of various dynamics. The Drainage Index is based on soil taxonomy, slope and aspect of NRCS soil units. As such the actual moisture holding ability may be much different dependent on variability within soil units, overstory effects and other dynamics. Additionally, FFE modeling is limited to within stand fire dynamics and is limited on how much it can inform how fire might move across the forest. Working with the day-to-day land manager, the school's resident forester, allowed for some identification of how various risk factors have occurred in the past which helped to inform how they might impact forest management in the future.

Use of the Climate Risk Metric revealed areas of extremely high risk within our forest properties as a result of strong dominance of at-risk coded species. In some cases, typically with sugar maple in northern hardwoods stands, the dominance of a given species was so strong that changing from calculations based on the "high climate" to the "low climate" projection scenario could change the CRM score of an individual stand from extremely high to extremely low. This reveals a critical consideration which must be taken into account when making use of this metric. If the CRM reveals a stand's dynamics to be heavily influenced by one particular species this may be a vulnerability or liability in and of itself. In response to this, increasing species diversity was identified as a high management priority rather than any transitions to or away from specific species. Even when considering alternative climate outcomes, it remains important to factor for global change factors such as invasive species and pathogens. Even under favorable climate, a stand heavily dominated by one species remains at risk from a lack of buffering capacity should some other risk factor be introduced against which it has limited resistance or resilience. The CRM remains a useful starting point from which to begin considering these dynamics, but it is important to note the resilience of a stand beyond simple climate influences when considering vulnerability.

4.1.3 Translating DFC's into Adaptation Actions

Identifying priority values and climate vulnerabilities are key initial steps. They are, however, meaningless if they are not translated into actions which respond to climate risks and seek to protect or maximize select values. Integrating the SMART concept (Long et al. 2010) allowed for the creation of objectives with specific metrics of success and associated strategies to help towards their achievement. Specific metrics of success also allowed for identification of signals of more reactive climate adaptation options which were designed to be implemented following failure of proactive measures. In this way, the plan was layered with contingency actions in addition to the pivoting ability allowed through adaptive management in order to best provide for response to unexpected outcomes and disturbances.

Success metrics allowed for accountability associated with each objective and all of its associated strategies by extension. By creating a pass/fail metric with each major action to be taken we made it such that we were able to evaluate not just whether we had achieved climate adaptation but also if we had properly carried out each of the steps intended to create the conditions necessary for climate suitability in the future. In this way the SMART concept is compatible with the concepts inherent in a climate focused adaptive management framework. The SMART concept also provides an additional filter when considering adaptation options. The requirement that achievability of actions be explicitly considered serves as an impetus for consideration of organizational capacity. An example of this can be seen again in the consideration of fire as a risk factor on the landscape. Recognition that the process to achieve greater ecological resistance and resilience to fire was not well known within the institution led to the decision to seek further analysis before prescribing specific actions. This analysis represents an achievable step towards the overall goal rather than a commitment to an uncertain task. This extra step allows for greater consideration of achievable future conditions as well as adding an extra check on the extent to which a management plan goes beyond aspirational objectives.

4.2 Business as Usual Vs. Climate Adaptation

Comparing climate change adaptation to business-as-usual requires first defining both concepts. Here we elect for an operational definition and define climate change adaptation as the range of planning measures and actions taken to ensure the longevity of predefined values into the future in the face of changing climate norms and global change. Often, preservation of levels of biodiversity and ecosystem services are an assumed to a goal in climate adaptation, but at an operational level the identification of specific values remains critical.

Defining business-as-usual is somewhat more difficult. The simplest definition would be forest management actions which are unrelated to climate adaptation. However, this assumes that BAU actions are always incompatible or unrelated to climate adaptation when in reality such actions may still represent the best course. For instance, managing for resistance to invasive pests and plants is business-as-usual as it is not management directly aimed at adapting to climate pressures. In actuality, such a measure represents more of a gray area between categories as it may be a preexisting concern or invasive species control may be increasingly prioritized as a result of a change in focus towards climate adaptation. For this reason, we refer to business-as-usual and climate adaptation as representing portions of a spectrum of categorizations for management actions. For the sake of comparison here we will use the Ogden and Innes (2007) definition and refer to actions which prioritize maintenance of the status quo rather than enhancement in light of greater uncertainty as business-as-usual. Forward thinking action and intent is emphasized in climate adaptation (Millar et al. 2007; Swanston et al. 2016) where business-as-usual can generally be characterized by ad hoc prescriptions which constitute reactions to unexpected perturbations and changes in priorities.

4.2.1 Where Have We Done CCA vs. BAU?

Determining an ideal ratio between BAU and CCA is subjective and highly dependent on the context of the plan. The level of vulnerability and the number of risk factors and at-risk stands are likely a primary determinant of how much of a management plan should be dedicated to climate adaptation. If, for example, the level of risk for the area of interest of a plan is minimal then it stands to reason that the level of attention given to climate adaptation would be limited. Similarly, if factors of high risk were limited to a few stands or risk factors were uniform across the area of interest, fewer solutions would be necessary translating to fewer action items within a management plan, but not necessarily less activity. However, fewer risks requiring a management response does not necessarily preclude from planning for the uncertainty around climate outcomes on some level and so actions should still seek to increase functional diversity and resilience. Normal operational priorities also have an impact on the proportion of CCA to BAU. If the focus of operations on a forest are shifting unrelated to climate change at the same time as adaptation is being considered, the relative proportion of each category of actions may be affected. In short, there is no ideal percentage that CCA should represent within a plan, but forward-thinking actions should still be significantly represented. Quantifying the relative proportions of each category as seen above provides a means to assess whether the level prescribed actions focused on adaptation is appropriate given the level of climate vulnerability and the planning context.

On our land base, a range of risk factors affected a range of ecosystem types and general promotion of adaptability was also a priority. As such, it was necessary that CCA and SYN options represented a greater proportion of the management recommendations. Our land base was divided between northern hardwoods, pine dominated, and mixed hardwood-softwood stands. Risks, at varying levels, included lack of species diversity and simplification of stands, drought, fire and other disturbance, and attacks from insects and pathogens. Dealing with the various combinations of forest types and risks required a greater range of planned management activities. Initial conditions and substrate limitations on species diversity also required a greater variety of solutions aimed at promoting stand-level adaptation. As we also engaged in a complete reconsideration of our forest management policies, a number of non-climate adaptation focused actions were also prioritized which aimed to enhance or create values related the forest's main priority as a place for teaching, research, and demonstration of forestry principles. As a result, at both the objective and strategic levels, the distribution of climate change adaptation focused actions versus BAU is about half and half.

4.2.2 How Do We Know Planned Actions Are Truly Adaptation?

Until some unknown time in the future when all planned management actions have been performed and the progressive effects of climate change have been seen, it will be impossible to truly determine if a state which is adapted to future norms has been achieved on the landscape. Here, we base the assertion that planning for climate adaptation has been achieved on three criteria:

1. Preservation or enhancement of specific values in light of changing climate
2. Response to specifically identified vulnerabilities and risks on the landscapes
3. Enhancing the adaptability of the system

All action items categorized as CCA or SYN achieve one or more of these criteria. In general, all actions which fit on the CCA half of the spectrum achieve the first criterion. Actions such as drought suitable plantings and silvicultural actions as well as alterations to stand structure to reduce risks of catastrophic fire achieve the second criterion. The third criterion is achieved through those actions which enhance the buffering and self-organizational capacities of the various forest types. These include actions which focus on promoting greater heterogeneity in stand structure and composition as well as greater forest and landscape level heterogeneity.

The major contemporary literature on climate change argues that because climate change is so spatially and temporally variable it is difficult to predict the exact climate outcomes that will occur in the future and therefore the appropriate response is to plan for uncertainty and high variability (Millar et al. 2007; Ogden and Innes 2007; Janowiak et al. 2014b). As such, a major component of climate change adaptation is to improve the adaptability and self-organizational capacity of a system rather than attempting to prepare for a specific set of future conditions (Millar et al. 2007; Puettmann 2011). From an ecological perspective this would involve enhancement or protection of the buffering ability of an ecosystem through promotion of response diversity (Elmqvist et al. 2003), structural heterogeneity at various scales (Puettmann 2011), and genetic diversity within species (Butler et al. 2012). The plan provides for proactive or contingency actions related to all these elements.

The unpredictability inherent in management for climate change also requires consideration and adjustment of organizational capacity (Gray 2012). In response to this the plan includes contingency actions to account for uncertainty in responding to disturbance or unforeseen changes in species suitability. Assessments are included as a part of the plan in response to areas where organizational knowledge is limited, such as fire resistance. Additionally, emphasis has been placed on rededicating resources to monitoring to allow for informed decision-making at all time-steps and to improve accountability related to success metrics of plan objectives.

4.2.3 How Would the Plan Differ Under BAU?

It is entirely speculative to think about how the plan might have differed without consideration for climate change adaptation. However, it is possible to make such an educated guess based on previous management policies and the general, broad range of contemporary forest operations within the region. This is especially true when one considers that climate adaptation does not necessarily equate to a whole new set of silvicultural treatments, rather a shift in the context in which many of traditional methods are applied with the addition of some new ones (Millar et al. 2007). As such, climate change adaptation is less about a specific range of actions to be taken and more about how forest management decisions are made. With this taken into consideration, it is possible to list a few major themes that would have varied had climate change adaptation not been the major theme guiding planning.

Immediately and most obviously, climate factors such as drought, heat stress, and increased fire risk would likely not be considered within the plan. A major theme in the plan is monitoring the ability of species to survive on a site with regeneration as the major signal for failure. Without consideration for climate instability forest management would likely be focused entirely on maintaining stocking rates with some reactionary efforts being taken to respond to regeneration failure. Fire has always been a component of jack pine systems (Nyamai et al. 2014; Tardif et al. 2016) but consideration for fire as an increasing disturbance might be excluded from the plan in the absence of climate considerations. Especially where resilience in the face of climate change is removed as a goal. Fire strategies may also be reactionary in the form of suppression and replanting, but fire would likely be dealt with more as a stochastic factor rather than a growing risk. Assisted migration in response to loss of species suitability would also likely either not be considered, or only be considered as an ad hoc response rather than a climate change contingency that with preparative measures taken into account early on.

The historical range of variability in conjunction with the primary management goals and regional silviculture guides would likely be the primary determinants of management actions. Predetermined values would likely still guide management priorities and successful regeneration would likely still be an implicit goal, but consideration that this value might be under greater threat would not occur. It is difficult to speculate on how threats such as invasive species and pathogens would be treated under a business as usual plan. Recent history provides somewhat of a window into this.

In general, the threat represented by potential invasion driven mortality is considered on a species by species basis and at a regional scale has generally been reactionary with proactive action taken only once the threat is detected in a certain proximity to the resource of interest. Such has been the case with the response to emerald ash borer (Kovacs et al. 2010; Herms and McCullough 2014). This approach has not been an inappropriate response to pest species invasion, but climate change will likely increase the threat posed by invasive insects and pathogens (Logan et al. 2003). The difference between factoring for adaptation or not would be proactive buffering against unforeseen outbreaks of native and non-native pests and pathogens. As such, it can be assumed that under a business-as-usual framework, species invasions and pest outbreaks would be dealt with on an ad hoc, reactive basis.

Climate change adaptation represents the difference between planning for a future of increased risk and threats to forest management goals and reacting to problems as they arise. Climate change adaptation requires planning for uncertainty and a range of future conditions where business-as-usual involves planning towards the HRV or a very specific range of desired conditions. As such, under a BAU plan, a focus on resilience and buffering capacity as well as adaptive management would likely be diminished. Uncertainty still exists within non-adaptation focused management planning centered around concepts such as global change and economic uncertainty, but these generally are only considered as far as the next stand rotation in many cases. The main difference between CCA and BAU is that decisions surrounding uncertainty and unforeseen consequences are made at different time-steps within a planning context. Under CCA, preemption of a range of risks is favored and preparation is emphasized to prepare for response. Under BAU decisions related to surprise climate and global change driven events would be made at the time of event occurring or later.

4.2.4 Climate Adaptation Vs. Management of Novel Ecosystems

Climate change adaptation and management of novel ecosystems both seek to maintain some predetermined function in light of anthropogenic changes to environmental conditions (Hobbs et al. 2006; Millar et al. 2007). In the case of novel ecosystems, the novelty occurs because of a loss of a particular component and a subsequent overwriting of ecological memory such that a return to a previous “historical” or “original” state is impractical or impossible and so new assemblages of native and often nonnative species emerge (Hobbs et al. 2006, 2009; Higgs 2017). Under climate adaptation transitions in species makeup and cover types are considered and sometimes implemented in order to preserve some designated ecosystem service of interest (Millar et al. 2007; Janowiak et al. 2014b). Novel ecosystems can occur as a result of climate adaptation but are not necessarily inherent to its undertaking. Where novel species assemblages are inherent to novel ecosystems, climate change adaptation may simply involve novel drivers. CCA is often characterized by novel combinations of climatic and site conditions (Swanston et al. 2016) responded to with novel applications of preexisting management techniques (Millar et al. 2007). Novel ecosystem management constitutes an acceptance of an overwritten system which cannot be restored where CCA seeks more of a rearrangement with enhancement of critical ecosystem components. One could argue that assisted migration in support of climate adaptation constitutes novel ecosystem management but in this case the question of novelty is a function of scale where often newly created species assemblages at a given location are not novel at a regional scale. At very local scales and depending on the intensity of management, novel ecosystems may form as a result of climate change or climate adaptation actions, but this will generally be controlled by the level of acceptance of nonnative species of a given organization.

The novel ecosystem concept is a social construct which must be viewed in light of values-based decision making (Backstrom et al. 2018). Here, we assert that climate adaptation is also largely values-based in that a set of values must be initially identified as the target of adaptation. A major argument underlying the novel ecosystems concept is that acceptance of novel assemblages will be necessary as much of these changes will be unavoidable as a result of climate change, but the extent to which ecosystems will be changed at a given location is uncertain (Murcia et al. 2014). The climate risk metric allowed for the revelation of the proportion of the live trees which were at risk in a stand, but not necessarily the proportion of at-risk components of a stand with high conservation or economic value. As such, the extent to which an individual species decline in a stand will require active intervention in the form of assisted migration or deviation from management in favor of an endemic forest type in order to conserve ecosystem services remains to be seen. Control of invasive species and management for endemic cover types is still a priority within our management plan. Response to species declines, generally signaled through regeneration failures, is planned for in the form of assisted migration but regionally-native species are still favored within the planning framework and thus the degree of novelty even in these contingencies is debatable. While novel assemblages and ecosystem types may still result on patches of the area of interest covered in the plan, acceptance of novel ecosystems is still limited to the most pragmatic eventualities.

4.3 Future Needs for Climate Adaptation

Success metrics for contemporary climate adaptation are based on user-defined benchmarks within an adaptive management framework (e.g. Swanston and Janowiak 2016) or on a set of predefined principles for forest management (e.g. Ogden and Innes 2007; Williamson and Edwards 2014). This design is centered around a desire for flexibility in order to promote implementation by land-managing organization and drive buy-in by land managers in response to previously identified barriers (e.g. Janowiak et al. 2014b; Halofsky et al. 2016). Where specific values are identified and prioritized this approach is generally broad enough to be appropriate in most situations provided the appropriate management options are selected and applied. However, unforeseen climate and global change factors or inappropriate adaptation options can lead to maladapted forest cover that is only revealed over time. Adaptive management allows for pivoting of management in response to such occurrences, but valuable resources may still be lost or degraded. Proactively planning for uncertainty is considered an essential component of climate adaptation (Millar et al. 2007) and this is achieved through bolstering the resilience of forested systems through silvicultural interventions or through promoting transitions to more future-adapted states (Puettmann 2011; Janowiak et al. 2014b).

As previously mentioned, concepts such as resilience and adaptability lack a unified definition and as such can be difficult to measure. Currently, setting resilience or adaptability as a goal requires that this condition, or attributes related to this condition, be defined and managed towards. This leaves open the possibility of incorrectly identifying underlying factors resulting in management actions that do little to bolster the adaptability or resilience of a system. Metrics for measuring the various components which make up resilience are needed to better guide climate adaptation efforts.

Functional trait diversity (Tilman 1997) and response diversity (Elmqvist et al. 2003) offer potential indices of resilience to be applied in forest management. Both represent a shift towards focusing on buffering of ecosystem services rather than base diversity of species in a given area. The difficulty of measuring component attributes and calculating functional diversity for a system (Cadotte et al. 2011) likely constitutes a barrier to its application in forest management. Creation of functional or response trait databases for use in conjunction with standard forest inventory data could improve the ability of forest managers to target management beyond simple species diversity where resilience is a concern. Structural complexity is also cited as being closely linked to the self-organizational capacity of a system (Puettmann 2011). However, for a forest management operation this can also be difficult to measure practically. No unified convention on measuring stand complexity exists although efforts have been made towards cataloging the related attributes (McElhinny et al. 2005). Improving and standardizing measurable metrics for forest resilience and complexity could help towards improving implementation of management actions seeking to enhance these attributes. Such indices would allow for the determination of whether or not the adaptability of a system has truly been achieved. While an adaptive management approach would still be useful and pragmatic, this would allow managers to more quickly determine the efficacy of adaptation actions and to redirect management with greater efficiency.

4.4 Conclusions

Climate change will require a management response to protect the continuity of some human values via ecosystem services in forested systems. Frameworks such as the Climate Change Response Framework and others provide a useful basis for framing an approach to climate adaptation from the ground up. Through application of the principles of these frameworks, we have found that identifying priority values early in the management planning process while recognizing future climate uncertainty will improve the ability to generate meaningful, effective management actions. Recognition of organizational limitations and potential flaws in the decision-making process can help to improve planning outcomes. We have proposed a logical way to assess decision-making outcomes in a climate adaptation planning context. Vulnerability indices are useful for identifying areas of risk in a forest, but a general focus on adaptability is still necessary to respond to future climate uncertainty. Operationally, climate change adaptation refers to the broad category of planning and management measures undertaken to protect specific values from the negative effects of anthropogenic climate change. Climate change adaptation involves measures to promote the resistance and resilience of specific values as well as those to promote the adaptability of a system or actively transition to a new, future-adapted state. Here we have defined a climate adapted system as one in which the longevity of priority values is provided for through protective measures or a focus on adaptability to uncertain change by enhancement of functional diversity and structural complexity. We have identified some functional gaps in the climate adaptation literature and suggest that future research should focus on improving metrics of these two attributes in order to allow for improved targeting of management actions towards real achievement of climate change adaptation.

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6 Appendix 1 – Management Planning History of the Ford Forest

6.1 Introduction

The purpose of this document is to inform goal and priority setting discussions pertaining to the Ford Center and Forest (FCF). This document serves as a summary of previous reviews and plans for operations on the forest. It should not be interpreted as representing the goals and priorities for forest management going forward but instead as a compilation of previous work in these areas. This document was prepared in anticipation of a series of meetings for the establishment of goals for a new forest management plan for SFRES Research Forest Lands.

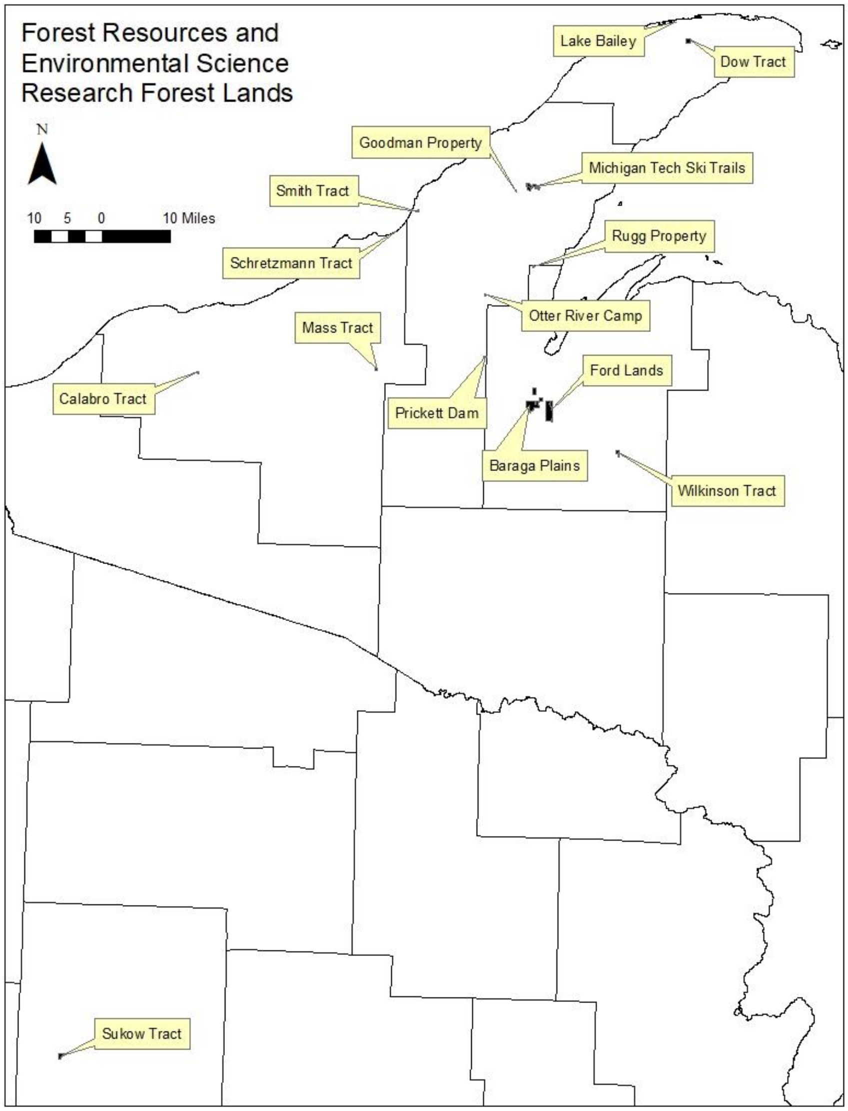

Figure 7: Map of the locations of Ford Forest Lands.

6.2 Tract Summary

Table 2: SFRES Research Forest and Managed Lands (sorted by year of acquisition).

Tract Name	Legal Description	County	Acreage	Date of Gift	Donor Name	Donor Intent	Deed Restriction
Ford Lands	Sec. 18,19, 30 T49N R33W	Baraga	1703	1954	Ford Motor Co.	Education, Research	None
Baraga Plains	SW ¼ Sec. 12, W ½ Sec. 2, Sec. 15, E ½ & W ½ NW ¼ Sec. 14 NE ¼ & NW ¼ SE ¼ Sec. 22, NW ¼ NW ¼ Sec. 23	Baraga	1894	1957	MI DNR	Education, Research	Revert back to State

Prickett Dam	N ½ SE ¼ & SW ¼ SE ¼ Sec. 9 T50N R35W	Houghton	123	1945	MI DNR	Education	Revert back to State
Otter River Camp	SE ¼ SW ¼ NE ¼ NW ¼ SE ¼ Sec. 25 T52N R35W	Houghton	20	1955	MI DNR	Education	Revert back to State
Mass Woodlot	SW ¼ SW ¼ Sec. 23 T50N R38W	Ontonagan	40	1965	USDA	Land Swap	None
Dow	Portions of Sec. 13 & 14 T58N R30W	Keweenaw	301	1973	Gordon and Eleanor Peterson	Education, Research	None
Smith	SW ¼ NE ¼ Sec. 29 T54N R36W	Houghton	40	1983	Charles and Susan Smith	Gift	None
Rugg Property	Gov. Lot 2 (NW ¼ NE ¼) Sec. 6 T52N R33W	Baraga	36	1986	Marjorie M. Rugg	Education	Endowed Scholarship
Wilkinson	NE ¼ & E ½ SE ¼ Sec. 23 T48N R32W	Baraga	238	1995	Thomas and Christine Wilkinson	Education	None
Goodman	Portion of NE ¼ NE ¼ Sec. 10 T54N R34W	Houghton	15	1997	Ben Goodman and Ann Thrasher	Education	Scholarship
Lake Bailey (For Sale)	Gov. Lot 5, Sec. 3, T58N R30W	Keweenaw	1.5	2005	Bailey Land Development Partnership	Unknown	None
Calabro	E 1/2 NE 1/4 NW 1/4 Sec. 33 T50N R42W2	Ontonagan	20	2011	Mayme Calabro	Education	None
Schretzmann	Gov. Lot 4, Sec 11, T53N R37W	Ontonagan	0.5	2015	Charles Schretzmann	Unknown	None
Sukow	NW 1/4 Sec. 30 ; NW 1/4 SW 1/4 Sec. 30; SW 1/4 SE 1/4 Sec. 30 T32N R5E	Lincoln	247	2015	Wayne and Carol Sukow	Unknown	Wisconsin Managed Forest Land
Tom Ala Property	Small lot within Gov. Lot 5, Sec. 32 T59N R28W	Keweenaw	0.5	2012	Tom Ala	Education and Research	10 Year reversion if not used
Nara Property	NE ¼ of NE ¼ & W ½ of NW ¼ & NW ¼ of SW ¼ Sec. 16 T54N R32W & S ½ of NE ¼, S ½ SW ¼, N ½ of SW ¼ & SE ¼ of Sec. 17 T54N R32W & E ½ of SE ¼ of Sec. 19 T54N R32W & N ½ of NW ¼ of NW ¼ of Sec. 20 T54N R32W	Houghton	270	2018	Ruth L Nara	Education and Research	

Other Michigan Tech Forest Properties (past management support from SFRES)

Tech Trails	E ½ Sec. 1 T54N R33W NW ¼ & NW ¼ SW ¼ & SW ¼ NE ¼ Sec. 6 T54N R34W, & part W ½ W ½ Sec 5	Houghton	620	N/A	Purchased	Campus Expansion/Recreation	None

6.3 Forest Management Plan

The FCF has a "draft" management plan that has been periodically updated by Jim Schmierer since the late 1990s. The most recent version is from 2010. According to the plan:

- Activities on the research forest should seek to fulfill one of the primary missions of the School of Forest Resources and environmental science: Teaching, research and outreach.
- Management activities on the forest, including harvest, should be self-funding from harvest revenues. Net revenues should serve to fund the Ford Center and village of Alberta until the facilities are solvent at which time funds will serve to support research and long term demonstration areas for education.
- Forest management activities carried out on the Forest will be consistent with the principles of:
    - The American Forest and Paper Association (AF&PA)
    - Sustainable Forestry Initiative (SFI)
    - The Forest Stewardship Council (FSC)
    - The American Tree Farm System (ATFS)

(Research and Forest Management Plan 2010)

6.3.1 Strategic Review 2012

In 2012 the FCF Advisory Committee proposed a "strategic review" of the Forest in anticipation of a formal revision of the management plan. The review was only partially completed, though one major outcome was the development of a vision statement for the Ford Forest. Some conclusions, briefly:

- Primary purposes of the **<u>Research Forest</u>**, in order, were found to be: education, research and teaching
- Secondary purposes included: Grad student training, visibility, outreach, revenue, recreation, and demonstration of sustainable forest management
- Areas identified for improvement centered around: Management, communication, accountability, development of performance standards, fundraising, strategic planning, and development of a unified vision.
- Hindrances to improvement: Ineffective management at all levels, state of facilities, debt/state of finances, harvest schedule, lack of a cohesive management plan, data quality, and nostalgia

- **Vision statement:** *Our vision for the Ford Forest is to be a recognized home of world class forestry and environmental field research.*

6.4 Draft Strategic Plan for the Ford Center and School Research Forest, 2015

The FCF Director completed a draft strategic plan for the FCF which was presented to the faculty in spring 2015. The strategic plan incorporated the vision statement developed earlier, and went much further defining a mission statement and substantial list of goals, objectives, and strategies for both the Ford Forest and the Ford Center. Those that relate to the forest, include:

- **Vision:** The Ford Center and Research Forest will be a world-class home of forestry and environmental field education and research
- **Mission:** Provide an ideal setting for field based education, research and demonstration in sustainable use of forest-based natural resources
- **Goals:**
  - Upgrade Ford Center facilities to reduce operating costs and enhance the school's ability to provide distinctive, field-based education in the assessment and sustainable management of forest-based natural resources.
    - *Objective 1.4 Provide high speed computer and wireless access throughout the FCF*
      - *Strategy 1. Install fiber optic to FCF to office, dorm, and computer lab and install wireless nodes throughout the dorm*
      - *Strategy 2. Install a communications tower to enable wireless access to field sites across the Ford Forest*
  - Demonstrate best practices in traditional forest management techniques and implement adaptive management and novel interdisciplinary approaches to tackle contemporary issues.
    - *Objective 2.1. Complete a planning-level resource inventory of School Research Forest based on permanent sample locations and implement a schedule for regular remeasurement.*
      - Strategy 1. An inventory was designed and implemented for Ford Forest lands near Alberta in 2010, and a similar inventory is being conducted for the outlying properties (started in 2013 by School Forester)
      - Strategy 2. Schedule regular remeasurement of inventory locations as part of revised forest management plan
    - *Objective 2.2. Revise the management plan for the School Research Forest with input from the Committee and SFRES faculty and staff. We will welcome input from interested Advisory Board members as well.*

        - **Strategy 1. Initial discussions of revisions to cutting methods and cycles and measures to enhance forest resilience/resistance to climate change**
        - Strategy 2. Familiarize new silviculturist with School Research Forest
        - **Strategy 3. Finalize revised forest management plan with input from School's silviculturist**
    - *Objective 2.3. Design and implement novel management approaches for dealing with contemporary issues and test these across the variety of climatic and soil conditions in which our forest ecosystems occur.*
        - **Strategy 1. Development of management strategies to increase resistance/resilience to climate change, invasive pests and other stressors**
        - Strategy 2. Find partners with whom to implement replicated tests of strategies
        - Strategy 3. Relevant post-treatment measurement of all silvicultural prescriptions to ensure adequate implementation and desired outcomes (important for student training)
    - *Objective 2.4. Follow best practices for forest management and obtain certification to verify this.*
        - Strategy 1. Address SFI, FSC and Tree Farm standards when revising forest management plan
        - Strategy 2. Obtain relevant certifications
        - Strategy 3. Apply for "Model Forest" status from the Forest Guild
- Improve facilities and opportunities for performing basic and applied research on plant and animal population and community dynamics and ecosystem structure and function.
    - *Objective 3.1. Provide on-site infrastructure needed for research.*
        - Strategy 1. Renovate the Carriage House into a lab that can support basic sample processing and analysis research conducted at the FCF
        - Strategy 2. Install a communications tower to enable wireless access to field equipment
    - *Objective 3.2. Key findings and research data from the FCF will be readily available on-line.*
        - Strategy 1. Develop a system using Microsoft Access to track status of all research projects and ensure a project abstract, annual updates and data are regularly requested for placement on the FCF website.
        - Strategy 2. Post project summaries and data for existing research on the FCF website using formats similar to those

utilized the NSF's Long Term Ecological Research program.

- Strategy 3. Post on-line (or link) all publications and technical reports generated by FCF research. Improve visibility of historic FCF reports already available on-line.
- Strategy 4. Develop an on-line request form for both internal and external parties interested in performing research at the FCF or outlying forest tracts

- Ensure both the Center and the Forest are economically viable, enabling funds to move between the entities that comprise the FCF as needed and allowing funds to also support needed non-revenue generating management activities, demonstration of novel management approaches and professional development.
  - *Objective 4.3. Establish an endowment to help support Center operations and maintenance, research, and student costs for IFP room and board.*
    - Strategy 1. Evaluate outlying tracts and sell those for which benefits from endowment outweigh their potential for forest products revenue and use in education and research.

7 Appendix 2 – Vulnerability of the Ford Forest to Climate Change

The vulnerability of the Ford Forest is spatially variable and dependent on a number of factors. Some stands are vulnerable as a function of species composition or structure alone where others are from soil moisture or landscape position. High density as well as homogeneity can be considered cause for concern owing to fire risk, resource competition, and a reduced buffering ability from a lack of species diversity. While risk to a stand from insect attack or disease is not explicitly considered in this assessment, it is assumed to be higher where diversity is lower. Other factors such as seed source and management history are considered here.

Worth noting is the fact that across all the northern hardwood stands of the Ford Forest is the potential for reduced snowpack and increased root frost. An increased number of freeze-thaw events across the area of concern in recent years and going into the future have the potential to reduce snowpack substantially during the winter months (Janowiak et al. 2014a). Decreased snowpack and the resultant soil frost has been shown to be associated with dieback in some areas of the northeastern United States (Groffman et al. 2001; Cleavitt et al. 2008; Auclair et al. 2010).

7.1 Vulnerability of the Ford Lands

Vulnerability on the Ford Lands is driven mainly by species composition. The stands comprising the tract are primarily of the northern hardwoods forest type, dominated largely by sugar maple with scattered inclusions of various conifer species. Under the high emissions future climate scenario (GFDL A1F1)(Janowiak et al. 2014a) sugar maple is slated to decline. As a result, the climate change risk metric is generally high for most of the stands comprising the tract. The risk metric for these stands decreases significantly under the lower climate scenario as a result of contrasting outcomes for sugar maple. However, in either case the lack of species diversity in many stands still represents a liability owing to reduced ecological buffering capacity.

Predictions of future species' suitability used in the regional vulnerability assessment underpinning the climate risk metric here are based largely on climatic variables (Janowiak et al. 2014a). Given potential changes in the seasonality and temporal patterns of precipitation (Janowiak et al. 2014a; Melillo et al. 2014) there is a possibility of significant detrimental impacts to stands from drought stress in the future. The drainage index elucidates where these effects may be more severe or buffered in the future.

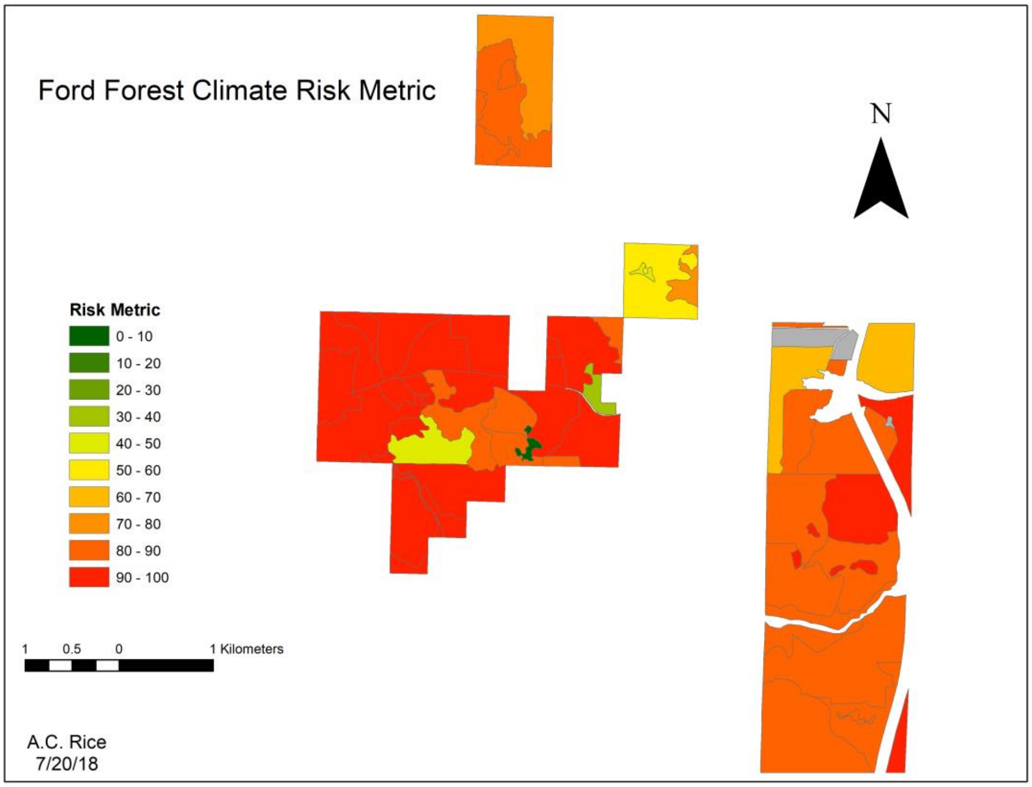

Figure 8: Climate Risk Metric Scores for the Ford Lands and Baraga Plains tracts. Gray areas indicate nonforested land or areas precluded from maangement planning.

The northern portion of the Ford Lands, comprising the stands surrounding the village of Alberta has a more moderate climate risk metric rating owing to species composition where tree diversity is somewhat higher (Specifically stands 33-39). However, the vulnerability in some of these stands (33-35, 37, a very small portion at the southern edge of 38) can be assumed to be much higher as a result of their location on coarse gravelly sandy loam with a lower drainage index score and a higher risk of drought stress. Portions of these stands have been associated with partial dieback in the seasons following particularly dry years. The partial western aspect of stand 36 along with a low drainage index score and a high risk metric score make it a particularly vulnerable stand. Portions of stand 40 are similarly vulnerable though a higher potential for moisture retention and greater compositional diversity ameliorate this. Vulnerability in stand 38 and 39 is likely lower than surrounding stands owing to compositional diversity and exclusion from the drier soil complex as well as topography. Stand 34 is largely excluded from this analysis as its entire area is encompassed by a silvicultural study precluding it from any other management activities.

Vulnerability on the central portion of the Ford Lands, spanning from the southern end of stand 39 to the north bank of the sturgeon river, is largely driven by topography. A lack of compositional diversity and steeper slopes generally raise the vulnerability of this entire area. Stand 42, which encompasses the peak of the large hill defining the area, can be interpreted as more vulnerable as a result of these combined factors. However, Stand 42 also has some of the most vigorous regeneration and so actual vulnerability may be different than scores indicate. For much of the rest of the stand a combined low drainage index score and high risk metric score lead to a likely much higher vulnerability. However, a few exceptions and potential refugia exist. Wetlands comprising stand 44 and contained within stands 43, 45 and 46 have a, predictably, much higher drainage index score. Their risk assessment score is high owing to dominance of eastern hemlock, a tree slated to decline in range under all climate scenarios, but their location in relatively wet, cool lowlands may buffer them from more extreme climate effects. Additionally, a wetter lowland in stand 45 contained in a bowl is likely to have a lower vulnerability than the rest of the stand and can potentially be designated as an area of climate refugia. At the bottom of the large hill, in the western portion of stand 43 and extending into stand 39, a soil complex with generally moderate drainage index scores may increase dieback risk following drought. Against the river the drainage index score is much lower owing to topography and a significant amount of exposed bedrock. Risk metric scores are high in this area making higher climate change vulnerability likely, however the area is designated as a buffer reserve and is generally precluded from management other than trail maintenance.

The Southern Ford Lands, encompassing all the stands south of the Sturgeon River, are somewhat more variable, in terms of potential climate vulnerability, owing largely to topography. Climate risk metric scores range between 80-90% for the majority of the area with the exception of stand 49 which has a score approaching 91%. Drainage index scores in this area are highly variable, ranging between 37 and 90 in a pattern that is fairly spatially variable. Scattered, relatively wet and cool depressions could act as buffer zones in this area as well as a few relatively wetter ravines, though moderate DI scores in these could lead to water stress at times. Similarly, a few areas with lower drainage index scores may represent zones of higher vulnerability, though the majority of the stand is generally rated mesic. Scattered groves of hemlock, and a sizeable hemlock inclusion making up stand 51, may be more vulnerable than surrounding northern hardwoods, particularly if the potential for hemlock wooly adelgid is considered.

Owing to species composition, fire risk on the Ford Lands is likely quite low. Torching probability for the area is extremely low. Some areas, particularly stands 37, 42 and the hemlock wetlands north of the sturgeon river as well as a few areas to the south and east of the tract have a lower threshold for crown fires based on the crowning index, but the torching index for most areas is quite high. While a few areas might have higher fire risk it can be assumed that the area would only be at risk of a damaging fire early in the growing season or under extreme drought conditions on a day with extreme fire weather.

7.2 Vulnerability of the Baraga Plains

Vulnerability on the Baraga Plains can be seen to be generally quite high driven by a number of factors. Homogenous species composition is possibly the most significant driver of vulnerability. The area, owing to predominantly dry, sandy soils, is dominated by jack pine with some pockets of white and red pine as well as some areas of black spruce swamp. Climate risk metric scores are generally between 90 and 100% for the entire tract although a few areas of extremely low density rate lower. A very large, sandy soil complex dominates the northern half of the tract. Additionally, the water table increases in distance from the surface northward along the tract. The southern half of the tract is significantly wetter, increasing in potential moisture until near saturation at its black spruce-dominated southern border. As such, more southerly stands have an increased likelihood of access to ground water in more well established areas than do stands on the northern portion. Areas of moderate soil moisture retention, and potentially lower drought vulnerability exist to the southwest of the tract.

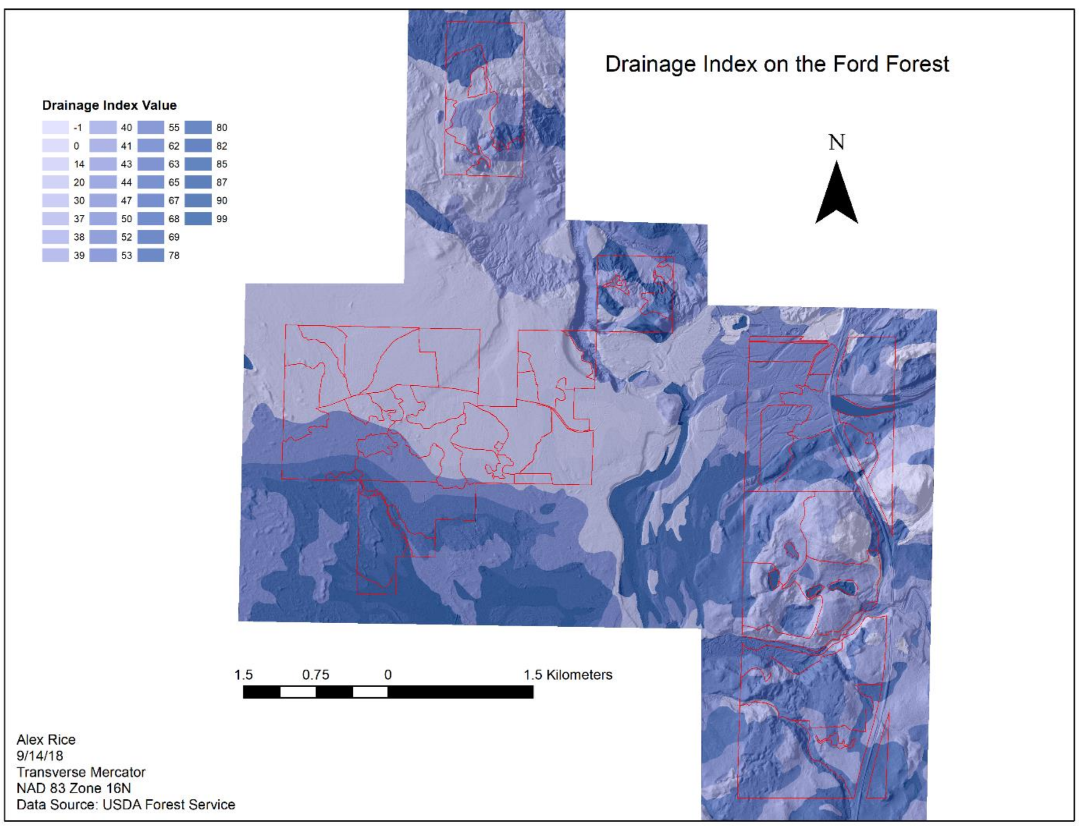

Figure 9: Drainage Index Scores for the Ford Lands and Baraga Plains Tracts. Data Source USDA Forest Service

Jack pine of a seed source observed to be less suitable and generating inferior stock are present in stands 8-10, 13, 14 and 19. The already limited suitability of the seed source to the area could lead to the conclusion that these stands are significantly more climate vulnerable. All the aforementioned combined factors point to 3 relative vulnerability classes on the Baraga plains: 1) the least vulnerable (though still vulnerable) southern portion of the plains with a higher water table and higher moisture holding capacity, 2) the central portion of the plains with lower moisture holding capacity but a local, better suited seed source, and 3) the northern portion of the plains, furthest from the water table with low moisture holding a capacity and jack pine of a less suitable seed source. The northeastern corner of the tract can be interpreted to resemble the central tract though it may be slightly more vulnerable owing to the water table. It should also be noted that past regeneration failures on the central Baraga Plains could potentially signify a future vulnerability.

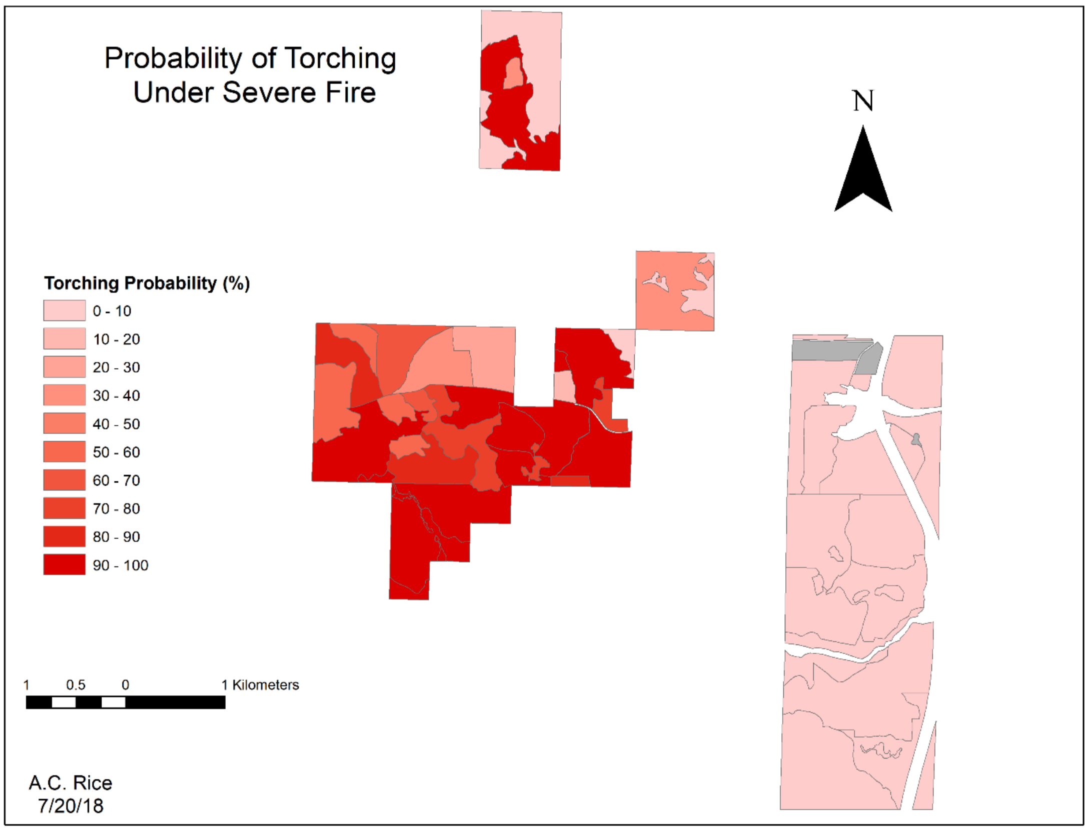

Figure 10: Torching Probability from 10 year projections using FVS Fire and Fuels Extension.

Fire risk on the Baraga Plains is likely very high owing to a combination of conifer dominance, dry soils, and stand structure. Torching probability under severe and moderate fire is generally very high (80-100%) for most of the stand with pockets of lower risk on the northern portion of the tract, though high probability in adjacent stands may increase the likelihood of a severe fire being carried over. Torching index ratings are generally low for most of the tract and crown index scores are similarly low throughout the center of the stand indicating a potential path along which a severe fire could spread in conditions that would only be considered somewhat severe.

7.3 Vulnerability of Section 12

Relative to the other tracts, the vulnerability of section 12 is much lower. Climate risk metric scores for the entire section range between 40-80%, with the majority of the area on the lower to moderate end of the spectrum. Species diversity and the presence of drought and potentially climate resilient red oak contribute to these more moderate scores. The area is generally dominated by red pine with mixes of oak, aspen and hemlock in various places. The soils in the area generally have moderate DI scores indicating an area that is relatively mesic, with a few areas of lower moisture holding capacity in the southwest and southeast corners. In general, the moderate vulnerability of this area make it a good candidate for resilience treatments.

Based on models, the fire risk for section 12 is somewhat moderate. Torching probability under a severe fire is relatively low. Torching index scores are in the range of lowest risk while crown index scores indicate a crown fire could occur in the lower ranges of wind speeds. The largest fire danger in this area is likely the potential for fire to spread from the higher risk Baraga Plains stands. Additionally, high levels of fine fuels build up at the ground level pose a risk.

7.4 Vulnerability of Section 2

Section 2's vulnerability can be interpreted to be relatively moderate though some attributes still make risk quite high. The risk metric for the area ranges between 70-90% owing to dominance of aspen, jack pine and birch, all slated to decline under the high climate scenario. A generally, higher diversity across the section may serve to increase buffering capacity, even if the species decline under modelled predictions. The north and eastern half of the section (Stand 1, MU 30) scores lower in terms of risk metric, likely as a result of the inclusion of red oak which could enhance the drought resilience of this particular stand.

Fire risk in section 2 is generally moderate. Torching probability is extremely high in the center of the section. Crown and torching index are generally moderate for the most of the section. Species composition is made up of more fire driven species but structure and a mix of northern hardwoods likely reduce the fire risk. Under more extreme drought conditions with high wind, severe fire might be more likely.

8 Appendix 3 – Ford Forest Management Plan Objectives and Strategies

Goal 1: Public and professional recognition of Ford Center and Forest as a teaching, research and demonstration forest including novel forest treatments. Links to the strategic plan with an aim to achieve goodwill amongst surrounding communities and partnership with other institutions and landowners for replication of novel treatments and greater engagement

Objective	Measure of Success	Timeline
1. Establish visible demonstration areas to showcase a variety of management activities.	• Sites representing each major disciplinary area (Silviculture, wildlife conservation and management, water conservation, forest ecology and management, timber production, recreation management) maintained to minimum standard and used in teaching and outreach.	Specific plan for each within 5 years

Strategies

- Rotate demonstration areas based on stand development and ongoing harvest
- Establish or maintain permanent water quality demonstration sites
- Establish a martelescope and a marked test plot for forest measurement and silviculture practice
- New research projects to include demonstration. Commitment of resources by Ford Forest/SFRES to support this end
- Demonstration of wood products usage on demonstration signage
- Upgrade roads and trails to permit visitor access

Objective	Measure of Success	Timeline
2. Maintain or increase the land base while focusing on geographic aggregation of land holdings.	• Land base (area of land owned by MTU SFRES) has grown or been maintained	Evaluation of land holdings every 5 years

Strategies

- Land holdings aggregated through land swaps with particular priority given to the land surrounding the village of Alberta
- Land sales of low value or net costly land parcels with revenue supporting further acquisition of strategically valuable tracts

Objective	Measure of Success	Timeline
3. Active management of the Ford Forest by a team of representative professional forest and natural resource managers.	• Staff position of school forester with professional credentials maintained • Continuous staffing of FCF committee by representative faculty with regular meetings	Immediate/Ongoing

Strategies

- School forester in charge of forest operations is SAF Certified and a Michigan Registered Forester
- Ford Forest committee composition should represent the major disciplines concerned with forest management

Objective	Measure of Success	Timeline
4. Leverage the presence of Alberta such that neither the forest nor village operates independently of the other.	• Clear opportunities for education and research to be hosted at the village • Resources flow bi-directionally between the village and forest	Immediate/Ongoing

Strategies

- Alberta will host researchers to promote active research on the forest
- strategic investment of forest revenues in village where forest operations are supported
- Novel forest treatments which will provide education and demonstration opportunities to classes and events hosted in the village
- Development of programs at Alberta in which the forest context is essential

Goal 2: Managed ecosystems with continuous forest cover and compositional diversity that set the standard for resilience goals in the region.

Objective	Measure of Success	Timeline
1. Manage northern hardwood stands comprising the Ford Lands Tract for increased tree species diversity and response to changing site suitability.	• Maintain or increase diversity of appropriate species based on metrics from forest inventory	Forest level metric assessed every five years

Strategies

- Employ variable retention harvesting and underplant marginal sugar maple dominated stands with limited or unsuccessful regeneration. This includes MU 33 (plant following harvest on MU 8), and MU 36-38, with more drought tolerant species including red oak, red maple and red and white pine. Underplant in clusters following next harvest to promote forest complexity

- Sugar maple on ideal locations: Manage in favor of sugar maple on more ideal sites with advance regeneration according to silvicultural guidelines. Establish zones of transition/diversification in MUs 33, 36-38 and sugar maple intensification in 42-43

- Allow results of the active silvicultural trials to guide northern hardwood management and diversification efforts

Objective	Measure of Success	Timeline
2. Manage for drought and climate resilience in stand structure and composition. Avoid loss of stand complexity.	• Species richness and Simpson's diversity index of North American native tree species within stands should be maintained. Alter composition following regeneration decline	Assessed with 5-year inventory rotation. Transition species within 5 years of regeneration failure

Strategies

- Protect the regeneration layer (from excessive herbivory, machine damage, etc.) and quickly transition areas that experience regeneration failure or dieback

- Mature trees in a given species can survive centuries past loss of suitable climatic conditions (Brubaker 1986; Noss 2001). Preserve legacy trees following harvest to allow for maintenance of locally adapted seed source during periods of less than ideal climate and to preserve essential forest network structure (retention, root structure, memory)

- In line with the concept of frequent low-intensity silviculture (Nolet et al. 2014), Employ a "worst first" marking guideline (except where individual low quality trees are maintained for habitat value) in order to maintain acceptable and unacceptable timber and to prevent loss of stand vigor in areas designated for intense sugar maple management (Stands 42-43, MU 3,6,10 North ½ of MU 7)

- Manage for species with a diversity of responses to environmental change (Elmqvist et al. 2003) and for structure that allows for response diversity to a variety of perturbations and change (e.g. a variety of regeneration strategies, individual species resistance and resilience).
- Within hardwood stands, monitor to identify clumps of a species which senesce at different times in order to guide management of composition in response to greater variability in growing season length

Objective	Measure of Success	Timeline
3. Manage the stands comprising the Baraga Plains for fire resistance. Alter forest structure to prevent increasing severity, spread of wildfires.	• An assessment and plan that produces measurable metrics of fire resistance	Within 2 years

Strategies

- Perform or contract out analysis for the generation of a report and/or plan

Objective	Measure of Success	Timeline
4. Experiment with assisted migration and hybrid species to find suitable replacements for species or provenances which may be extirpated by climate change.	• Opportunities to perform such efforts on the Ford Forest for interested researchers • Establishment of ornamental provenance trial	Within 5 years

Strategies

- Utilize regeneration failures to establish trials of species with potentially expanded habitat (as determined by Janowiak et al. 2014) and/or drought and climate resistant hybrid species – where research interests exist
- Use ornamental trees within Alberta as an informal provenance trial and seed source for assisted migration projects
- Summarize regional efforts and regional provenance data for decision support in preparation for potential assisted migration

Objective	Measure of Success	Timeline
5. Maintain forest cover across time by managing for successful regeneration following disturbance	• Achieve successful regeneration of desired species in all stands following disturbance	Prescription within 1 year of disturbance Target achieved within 5 years of disturbance

Strategies

- All prescriptions have a specified level of regeneration.
- Development of appropriate standards or prescriptions after natural disturbance
- Appropriate stocking based on forest type using silvicultural guidelines for desired species. Plant where appropriate stocking rates are not met within 5 years

Goal 3: Managed stands representative of a variety of ecosystems with varying forest types and successional stages as well as a variety of forest treatments across the land base.

Objective	Measure of Success	Timeline
1. Maintain a diversity of age classes and successional stages across all forest types with increased structural heterogeneity and species diversity across the landscape.	• Each of 4 classes of stand development (Sensu Oliver and Larson 1996) represented in each major forest type	Progress within 5 years; achievement in 200 years

Strategies

- Within the Baraga Plains and other sites with cover types where even aged management is appropriate, avoid uneven aged treatments, focus on retention within an even aged system
- On the Ford Lands Tract and outlying hardwood stands integrate different seral stages via patch or group selection combined with understory management (scarification, regeneration protection and management, planting)
- On the Ford Lands, Section 2, and Section 12 and outlying hardwood stands employ variable density harvesting at various scales (group, stand, multi-stand) in order to increase structural heterogeneity across and within hardwood and mixed stands
- Complete the geospatial and forest inventory databases in order to characterize current conditions on the forest. Project alternative management outcomes

Objective	Measure of Success	Timeline
2. Manage for landscape heterogeneity and complexity.	• Advocacy/participation within networks of regional and local managers	Immediate/Ongoing

Strategies

- Maintain up to date GIS database of stand and management unit attributes (See goal 7)

Objective	Measure of Success	Timeline
3. Identify and establish climate refugia.	• Refugia identified and documented • Loss avoided	Following 5 year inventory

Strategies

- Define "climate refugia"
- Identify, delineate, and define areas (See goal 7)

Objective	Measure of Success	Timeline
4. Identify unique sites that demand specific consideration	• Unique sites identified and documented • Loss avoided	Following 5 year inventory

Strategies

- Identify, delineate, and define areas (See goal 7)

Goal 4: Fire managed on the landscape as a major driver of forest types

Objective	Measure of Success	Timeline
1. Manage the stands comprising the Baraga Plains for resistance to uncharacteristic fire. Alter forest structure to limit fire severity and spread when it does occur.	• Immediate term: completion of analysis in support of determining actions to be taken • 5 years: fuel breaks installed and fuels treatments performed where deemed necessary	2 years to complete analysis 5 years to action taken

Strategies

- Perform or contract out analysis for the generation of a report and/or plan

Objective	Measure of Success	Timeline
2. Fire recognized as an inevitable and integral disturbance in ecosystems on a portion of the forest.	• Fire explicitly considered in the prescription process as a management option for areas designated as having fire as a major driver with justification for its use or use of silvicultural alternatives	Immediate for all new prescriptions

Strategies

- Delineate areas where fire is a major component requiring consideration
- Prescriptions for stands in areas where fire is a major driver incorporate consideration of fire as a management option
- Where fire is deemed unfeasible, prescriptions rationalize how fire effects are mimicked

Objective	Measure of Success	Timeline
3. Guide recovery following fire to prevent ecosystem conversion to non-forested systems.	• Achievement of appropriate stocking rates based on cover type (or desired altered cover type) within 5 years	Desirable stocking rates by 5 years following disturbance

Strategies

- Promptly following disturbance determine if recovery or transition is desired on disturbed areas. Prescribe action to achieve appropriate stocking of desired cover type.
- Plant stands to transition provenance or species assemblages

Goal 5: Invasive species and severe, climate change driven outbreaks of endemic pests anticipated, managed for, and controlled

Objective	Measure of Success	Timeline
1. Manage for tree vigor and resistance to insect and pathogen attack.	• Using stocking charts as measure of success	Immediate/Ongoing

Strategies

- Focus on stands of known at risk species including: eastern hemlock, red pine and white pine. Manage to B-line of stocking charts

Objective	Measure of Success	Timeline
2. Respond strategically to invasive species detection to quickly control and/or mitigate potentially damaging invasions.	• Threat assessment; response plan • At least no increase in species richness of invasive species, abundance, distribution	Immediate/Ongoing

Strategies

- Develop and deploy educational materials to facilitate detection by recreational users, students and create a vector for reporting detection
- Implement and follow through on periodic inventory in which establishment of invasives is monitored

Objective	Measure of Success	Timeline
3. Limit vectors for invasive species	• Improved infrastructure and procedures for prevention	Immediate/Ongoing

Strategies

- Develop procedures related to all field activities (e.g. monitoring, logging, in-field teaching) for limiting introduction of invasive

Goal 6: Protect productivity of terrestrial, riparian, and aquatic ecosystems and associated ecosystem services in light of anticipated climate change and resulting impacts.

Objective	Measure of Success	Timeline
1. Prioritize management of riparian areas and features to maintain function.	• Riparian zones mapped and incorporated into prescriptions • No reduction in maintained areas	Immediate for new prescriptions. Develop prescription within 1 year after natural disturbance.

Strategies

- Incorporate locations of riparian areas, vernal pools into GIS database (See goal 7)

Objective	Measure of Success	Timeline
2. Protect forest soils from disturbances related to forest operations	• Mitigation measures in place	Immediate/ongoing

Strategies

- Mitigation of compaction and soil rutting during all forest operations where soil impacts are possible

Objective	Measure of Success	Timeline
3. Manage for diverse site conditions and legacy elements to promote structural and compositional diversity	• Maintain or increase presence of appropriate legacy attributes (Sensu. McElhinny et al. 2005) based on metrics from forest inventory	Ongoing

Strategies

- In mixed and hardwood stands maintain more diverse stand structures and site conditions (gaps, downed wood, soil disturbance, etc.) in order to promote a mix of species that dominate at different seral stages
- Maintain legacy structural elements following harvest. Retain patches of down and standing dead wood as well as some mature live trees in stands following harvest
- Maintain clumps of mature seed trees in jack pine systems as insurance against loss of immature trees to fire (Retained clumps likely will not provide enough seed source to preclude the necessity of planting post-disturbance. However, legacy clumps will contribute to a more diverse stand and forest level mosaic which will promote long-term resilience).
- **Note:** It is important to recognize the lack of an objective definition for both the terms "maintain or increase" and "appropriate" as they are used here. To fully operationalize this objective in the long term this organization will need to determine the current status of structural complexity and legacy elements on the land base. Additionally, it will be necessary to, at least on a prescription by

prescription basis, come up with a method for determining the appropriateness of legacy attributes to maintain.

Goal 7: Creation of an adaptive forest management plan designed to demonstrate the management process, feature ecosystem services, and allow for adaptation of forest resources to global change.

Objective	Measure of Success	Timeline
1. Creation of a periodic report on the state of the forest including inventory and stand conditions	• Completed forest inventory • Delivery of report • Database of harvest info	Repeating/ongoing for a forest-wide inventory every 5 years Database of harvest info updated annually

Strategies

- Complete forest inventory
- Make resources available for the completion of regular forest inventory on a 5-year interval
- Create a user accessible database of harvest information.
- Track prescription targets spatially as well as pre and post-harvest conditions, integrate into GIS layer.

Objective	Measure of Success	Timeline
2. Incorporate monitoring towards the objective of adaptive management. Base forest management decision on the outcomes of previous management activities as determined by regular monitoring with a 5-year interval for complete inventory and revision of management plan.	• Completion of management plan revisions based on success/failures from previous intervals	Every 5 years

Goal 8: Sustained output of timber sufficient to finance state-of-the-art forest management activities and research

Objective	Measure of Success	Timeline
1. Manage for stand productivity and timber quality outside of designated reserves	• A harvest schedule	Harvest schedule within 2 years

Strategies

- Create a harvest schedule with planned harvests with the aim of relatively consistent income from harvest over time and serving to meet previously stated guidelines

Objective	Measure of Success	Timeline
2. Manage to allow efficient, minimally destructive access to all non-reserve stands	• Inaccessible areas minimized outside of designated reserves	10 years

Strategies

- Improve access/road networks in areas where such is limited (e.g. Ford Lands south of the Sturgeon River)

Objective	Measure of Success	Timeline
3. Ensure the financial viability of the Ford Forest over the short and long-term.	• A balanced budget on a rolling basis	Immediate/Ongoing

Strategies

- Develop an annual budget and year-end financial report
- Link the harvest schedule to a financial plan
- Make an institutional commitment that proceeds from forest management are used first to ensure regeneration of disturbed stands.