RAD Decisions in Rad Landscapes:
Minong, Isle Royale National Park

Final Report

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Executive Summary

Climate change is contributing to unprecedented rates of ecological transformation worldwide. Shifts in species composition and habitat have implications for ecosystem function and human relationships. The 1964 Wilderness Act was passed to preserve undeveloped large landscapes in their "natural" condition and for the continued use and enjoyment of people. Nevertheless, wilderness is still vulnerable to the direct and indirect impacts of climate change. Using active management to respond to climate change challenges in wilderness is complicated by the very protections afforded to wilderness that limit human impacts. This dichotomy manifests as a wicked problem for land stewards who are grappling with how to prepare for or respond to climate change-driven ecological transformation.

To untangle this wicked problem, scientists at the Aldo Leopold Wilderness Research Institute (ALWRI) worked with land stewards of Isle Royale National Park to apply the resist–accept–direct (RAD) framework to illuminate a decision space surrounding ecological transformation. The RAD framework is a climate adaptation tool that aids managers and their partners in generating a suite of management responses to either resist, accept, or direct observed or anticipated climate change-driven ecological transformation. Isle Royale National Park is a 40-mile-long archipelago situated within Lake Superior that is experiencing shifts in forest structure driven by changing climatic conditions. Ninety-nine percent of Isle Royale is designated wilderness, which makes addressing forest transformation particularly complex. Nevertheless, it's important for managers to mindfully select among alternatives to resist, accept, or direct observed or anticipated change to retain important ecological processes and relationships between people and the landscape.

The overarching goal of the *RAD Decisions in Rad Landscapes: Minong*[1]*, Isle Royale National Park* case study was to provide National Park Service (NPS) staff and partners from the Grand Portage Band of Lake Superior Chippewa[2] (Ojibwe; herein, GPLSC) with knowledge and tools to support intentional and transparent decision making for forest communities on Minong through climate change-driven ecological transformation. Scientists from ALWRI investigated potential ecological consequences of climate change for forests on Minong as well as managers' perceived ability to respond to ecological change. Additionally, scientists from ALWRI facilitated a 2-day workshop that engaged NPS and GPLSC staff in an adaptive management-based process to clarify values and desired conditions, generate decision alternatives using the RAD framework, and evaluate the potential social, legal, and ecological implications of various decision alternatives for forests on Minong.

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[1] Isle Royale National Park refers to the archipelago designated as a U.S. national park in 1940. Isle Royale National Park is part of the traditional homeland of the Ojibwe. "Minong" is the Ojibwe place name for the largest island in the chain.

[2] "Chippewa" is an alternative, Anglicized version of Ojibwe used frequently in U.S. treaties and in the United States.

Workshop activities and discussions were informed by biological and social science research conducted prior to the workshop. Biological analyses included dynamic forest simulation modeling using the LANDIS-II modeling environment for three climate futures and two management alternatives involving differing degrees of management intervention. Among all scenarios, two dominant ecological transformations were expected to occur: conversion of boreal forest to temperate forest and conversion of forest cover to other cover types (e.g., grass or shrub). Social science research included individual interviews with managers and management partners on their perceived capacity to address climate change challenges. NPS interviewees felt that low staff capacity and lack of clarity regarding what may be allowable under the Wilderness Act constrained their ability to address emerging ecological transformation, however, most staff felt that active forest management, such as prescribed burning, would be desirable pursuits. Because they observed ecological change occurring more slowly than on Tribal trust lands in mainland Minnesota, GPLSC interviewees viewed Minong as a climate refugium[3] for important spiritual and cultural relationships and practices.

During the workshop, attendees participated in a range of facilitated discussions and small-group activities to inform an iterative process of generating and evaluating decision alternatives to address climate change challenges for forest communities on Minong. The workshop was hosted in Grand Portage, Minnesota, USA, and attended by NPS and GPLSC staff. When applying the RAD framework, workshop participants largely generated management alternatives that accepted predicted forest transformation (e.g., research and monitoring in lieu of active management) or resisted transformation through active management. Participants were more likely to generate resist alternatives when considering an ecological type conversion from forest to non-forest. Alternatives that directed transformation included the strategic planting of native tree species predicted to respond positively to climate warming. Participants felt co-stewardship was important for implementing these alternatives and achieving shared desired conditions. In particular, much discussion focused on the application of cultural burning to improve forest health and restore relationships between people and the land.

The process and tools introduced in the workshop were created to support forward-thinking and intentional decision making regarding climate change-driven ecological transformation on Minong. Specific recommendations were not provided as part of this workshop because the intention was that practitioners, land stewards, and partners can use this process in a way that best fits their unique needs and limitations moving forward. Following a standardized process that explicitly integrates the evaluation of management alternatives can increase transparency in decision making, thereby fostering collaboration and facilitating defensible decision making in wilderness.

[3] Climate refugia are areas where climate change proceeds more slowly than in surrounding areas (Morelli et al. 2020).

Key take-aways

- Overall, boreal forest cover is predicted to decline on Minong via replacement by temperate forest species or conversion to a non-forested plant community
- Current management activities are projected to be ineffective at reducing or reversing expected forest transformation
- Capacity constraints and uncertainty regarding what activities may be allowable under the Wilderness Act impacts managers' ability to engage in active management to respond to climate change-driven ecological transformation
- There was widespread agreement on values and desired conditions for Minong among workshop attendees from the NPS and GPLSC
- Managers feel that using prescribed and cultural burning may be important for resisting ecological transformation as well as increasing forest resilience when coupled with planting climate-adapted species under a directing-change strategy
- Workshop participants agreed that co-stewardship was valuable and should be prioritized both in decision making and implementation

RAD Decisions in Rad Landscapes: Project Background

Ecological Transformation

Climate change has contributed to unprecedented shifts in ecological patterns and processes (McElwee et al. 2023). These changes directly and indirectly impact relationships between people and the environment. When compounded by existing stressors and threats such as wildfire, pests, disease, invasive species, and human development, ecological change can become irreversible. Ecological transformation, or the emergence of new ecosystem states that differ from known historical conditions in a site (Crausbay et al. 2022[4]), makes it difficult for land stewards and partners to delineate management goals and adhere to current management strategies (Stein et al. 2013). Growing concern and recognition that traditional or familiar stewardship strategies may no longer support resilient ecological communities has driven land stewards and their partners to seek alternative solutions to address complex problems under climate change (Magness et al. 2012; Schwartz et al. 2012; Schuurman et al. 2020, 2022).

Managing for Climate Change in Wilderness: A Wicked Problem

Climate change-driven ecological transformation is a diffuse and complex issue impacting landscapes globally, regardless of jurisdiction and protection status. In the United States, the National Wilderness Preservation System (NWPS) includes over 100 million acres of land afforded the highest level of protection of all public lands in the United States. Guiding policy under the 1964 Wilderness Act mandates that lands designated as part of the NWPS be preserved in their natural state, wherein the character of the landscape is primarily influenced by the forces of nature and absent of human development or trammeling (Public Law 88-577; Wilderness Act 1964). In addition, the NWPS is managed to preserve opportunities for solitude or primitive recreational experiences and other features of value, such as ecological processes and cultural features that existed upon designation (Table 1). Nevertheless, despite these high levels of protection, the NWPS remains susceptible to climate change-driven challenges such as increasing temperatures, altered precipitation patterns, and altered disturbance regimes. These challenges threaten several qualities of wilderness character, including the natural condition of wilderness, or the quality of an ecological system to be free from the impacts of modern civilization. These climate change-driven threats were not anticipated when the 1964 Wilderness Act was signed into law. Lack of guidance and sometimes competing priorities outlined under the Wilderness Act have created a conundrum for land stewards, rightsholders, and partners attempting to address climate change-related impacts within the NWPS. Furthermore, the same high levels of protection afforded to wilderness to protect lands from direct human impacts are often dually perceived as constraints on addressing climate change-

[4] Crausbay et al. (2022) define ecological transformation as a "shift in multiple ecological characteristics of an ecosystem, the basis of which is a high degree of turnover in ecological communities."

driven threats, including ecological transformation. Whether or not to pursue active management, which may involve trammeling, to address transforming wilderness systems presents a "wicked problem", or a problem that is seemingly intractable due to the high degree of complexity and uncertainty associated with balancing sometimes competing mandates, objectives, and values (Head 2019; Rittel & Webber 1973).

Table 1: Descriptions of wilderness character qualities and examples of ways in which they can be degraded are selected from Keeping it wild 2: An updated interagency strategy to monitor trends in wilderness character across the National Wilderness Preservation System (Landres et al. 2015).

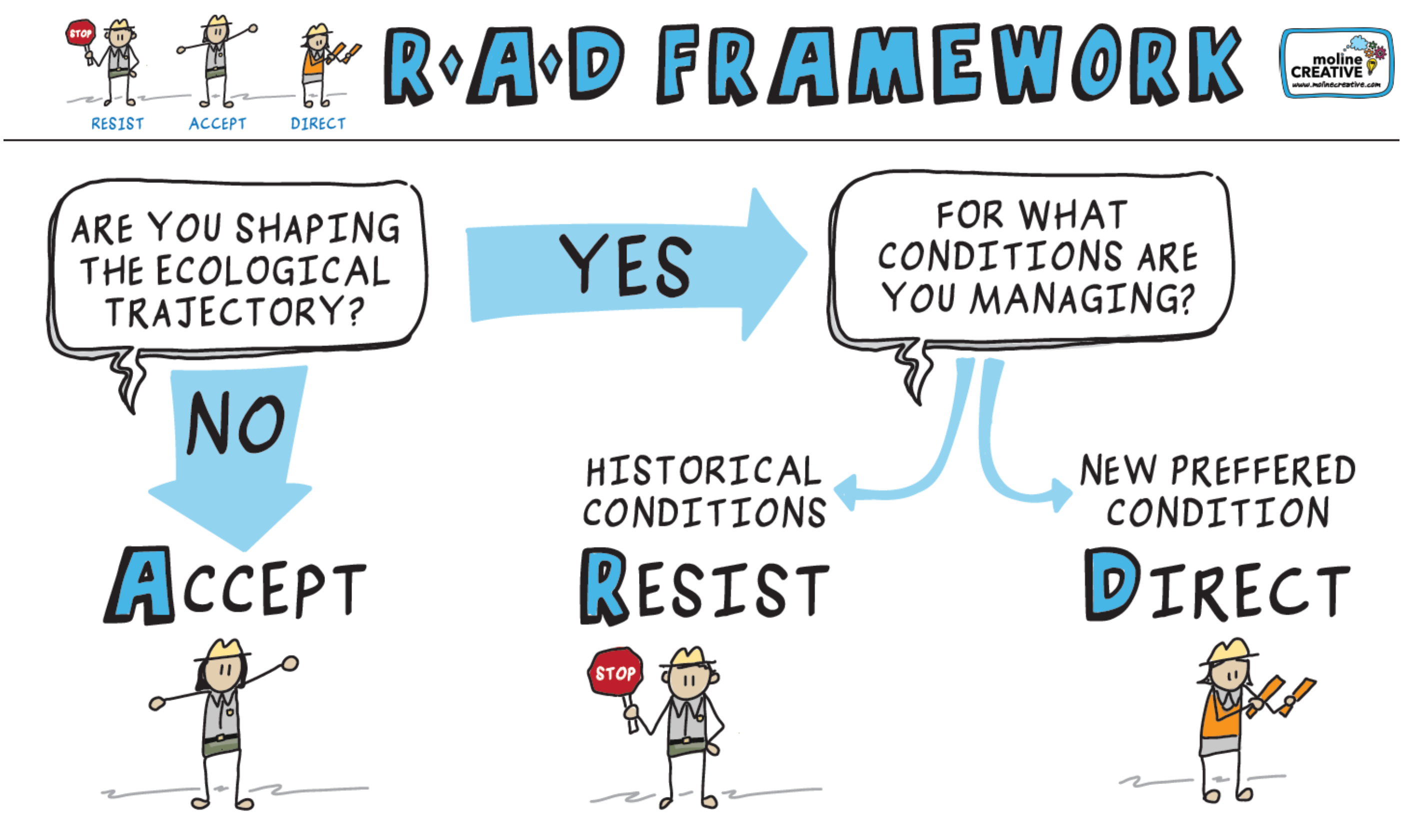
Wilderness Character Quality	Definition	Example Measures that Detract from Quality
Natural	Wilderness patterns and processes are largely free from the influence of modern civilization	Presence of non-native species, air pollutants, water pollutants
Untrammeled	Wilderness is free from the impacts of human activity or manipulation	Mechanical forest treatments, wildfire suppression, fish stocking
Undeveloped	Wilderness does not contain structures, installations, or other evidence of human presence or occupation	Dams, use of motorized or mechanized equipment, recreational kiosks
Solitude or Primitive and Unconfined Recreation	Wilderness provides opportunities for solitude and primitive recreational experiences unhindered by the impacts of modern civilization	Light pollution, recreation facilities, user-created campsites and trails
Other Features of Value	Wilderness preserves ecological, geological, or other features of scientific, educational, scenic, or historical value	Vandalism of existing cultural features, loss of iconic plant or animal species, deterioration of iconic geological features

Untangling the Wicked Problem: RAD

The resist-accept-direct framework (RAD) helps users explore the full range of available choices for addressing expected or observed ecological transformation: 1) Resist the transformation by maintaining historical conditions through efforts to prevent a transformation or engage in restoration to reverse the process, 2) Accept the transformation by intentionally allowing ecological composition, structure, and function to change autonomously, or, 3) Direct the transformation by actively shaping ecological change toward a preferred new condition

(Schuurman et al. 2022; Figure 1). RAD has a unique advantage for wilderness managers because of its incorporation of acceptance as a possible strategy, which supports wilderness as untrammeled. Interagency guidance describes the untrammeled quality of wilderness character as the "first among equals" (Landres et al. 2015, p. 80), which may lead some managers to prioritize the untrammeled quality of wilderness over others such as naturalness. However, instead of accepting ecosystem change implicitly to support the untrammeled quality, RAD provides a decision space wherein the relative value of acceptance can be fully examined and compared to alternative resist or direct strategies. Explicit and intentional planning fosters transparency in decision making, a quality which is particularly important in federally designated wilderness where active management is highly scrutinized (Miller et al. 2025). By intentionally choosing to resist, accept, or direct observed or anticipated ecological change, land stewards can begin to generate defensible solutions for addressing climate change challenges in wilderness.

Figure 1: Decision points to guide the use and implementation of the resist–accept–direct (RAD) framework for responding to observed or expected ecological transformation under climate change.



Project Objectives

To unravel the wicked problem of addressing climate change in federally designated wilderness, scientists at the Aldo Leopold Wilderness Research Institute (ALWRI) led an effort that used the RAD framework as a tool to illuminate the decision space when addressing climate change-driven ecological transformation for four case studies, one per wilderness-administering agency. Minong, Isle Royale National Park was nominated by National Park Service (NPS) staff as a case study that represented common challenges staff face when attempting to address climate change impacts in wilderness. Through this project and workshop, a process was developed to demonstrate the utility of the RAD framework for adaptive decision making for forest communities on Minong. Scientists at ALWRI worked with staff from NPS as well as staff from the Grand Portage Band of Lake Superior Chippewa (GPLSC) to identify values and desired conditions, use RAD to explore the decision space to meet those desired conditions, and evaluate social-ecological trade-offs inherent in pursuing RAD strategies.

The *RAD Decisions in Rad Landscapes* project had three primary goals:

1) **Generate a widely applicable process of how to use the RAD framework in designated wilderness.**

2) **Provide science and decision support for management challenges related to climate change in wilderness.**

3) **Advance our understanding of the trade-offs, uncertainties, opportunities, and limitations for addressing climate change impacts within designated wilderness.**

Project Stages

To accomplish overarching project goals, four project stages were completed for all four case studies (Table 2): 1) gather information to identify case study partners and to better understand current conditions within wilderness and challenges impacting wilderness management, 2) investigate biological and social impacts of climate change-driven transformation in wilderness, 3) facilitate workshops to clarify values and desired conditions as well as evaluate a RAD decision-space for current and future climate change challenges, 4) produce deliverables to summarize results of science analyses and comprehensive summaries of workshop activities. Each stage of the project was designed to inform and contribute to an adaptive management process using RAD as a tool to support intentional decision making around climate change-driven transformation. This report summarizes the first three stages of the project specific to the Minong, Isle Royale National Park case study.

Table 2: Project stages and descriptions for the RAD Decisions in Rad Landscapes project, 2022-2025.

Information Gathering	Investigate Transformation	Apply RAD to Planning Process	Final Reporting
Build Advisory Team **Synthesize Current Methods and Processes** **Establish Partners** **Site Visits** **Select Case Studies**	**Social Implications of and Perspectives Around Climate Change** • Interviews with managers, rightsholders, partners, and decision-makers **Biological Projections Under Climate Change** • Climate change and landscape change modeling • Clarify ecological transformation(s)	**Workshop to Apply and Evaluate RAD Decision Alternatives** • Identify and evaluate values and desired conditions • Generate RAD alternatives • Illuminate socio-ecological consequences of alternatives for wilderness management	**Post-Workshop Reports** **General Technical Report** **Peer-Reviewed Publications**

Information Gathering

Minong

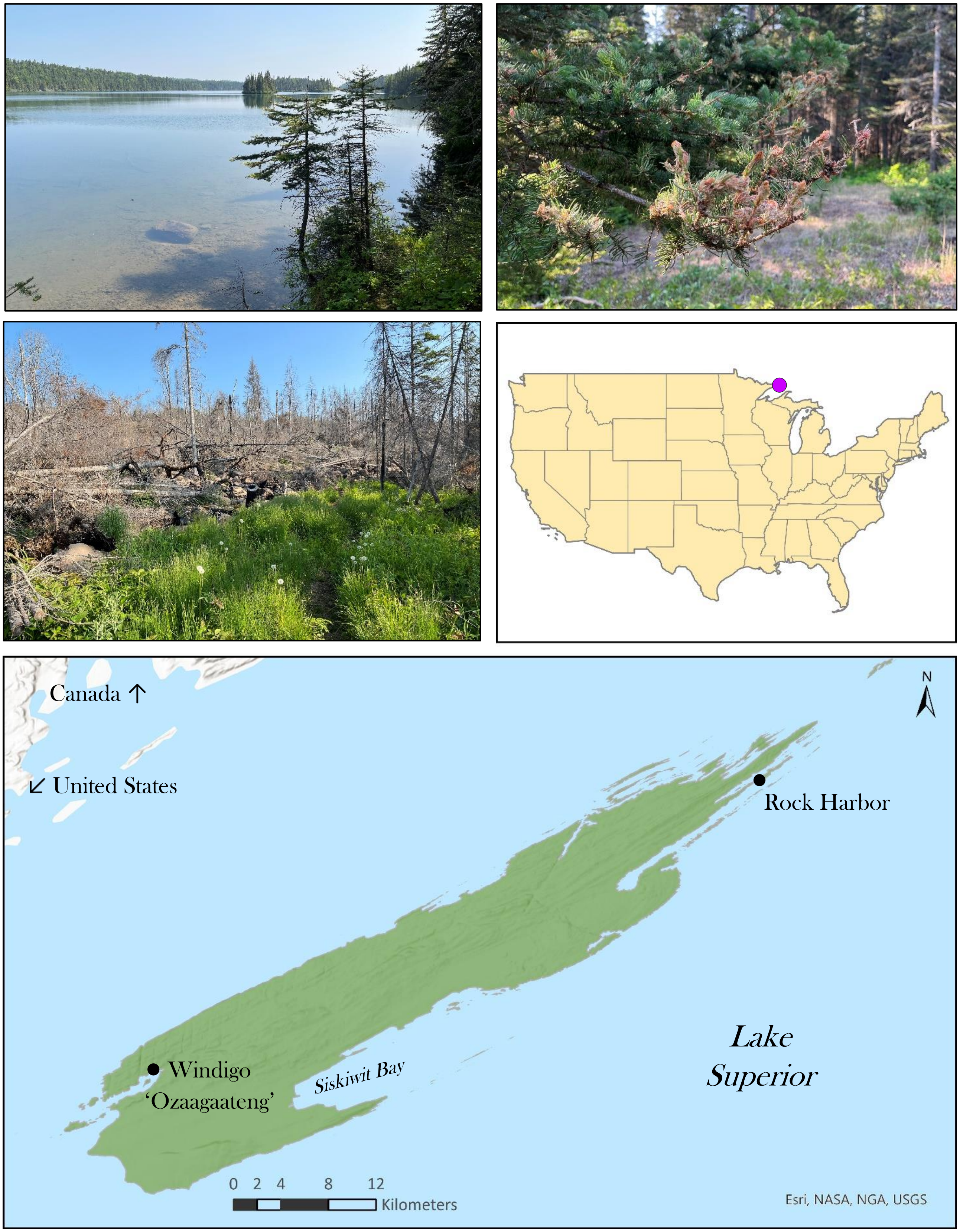
Minong, Isle Royale National Park Case Study

Isle Royale National Park is a 45-mile-long archipelago located in northwest Lake Superior, United States (Box 1). Minong, the Ojibwe place name for the largest island in the archipelago, is important to the cultural heritage of the Ojibwe people and is part of the ancestral lands of the Grand Portage Band of Lake Superior Chippewa (GPLSC). Some hold that Minong was not among the lands ceded to the U.S. government in 1842 because the GPLSC did not sign the treaty of 1842 (Heller 1987). Minong includes the southernmost extent of boreal forest in North America, and provides habitat for a host of charismatic species, including moose and wolves that originally became established on the island in the early 1900s (moose) and mid-20th century (wolves) following extirpation of lynx and caribou by Euroamerican settlers (Vucetich et al. 2012). Ecologically and culturally significant boreal tree species on the main island include trembling aspen (*Populus tremuloides*), white and black spruce (*Picea glauca* and *Picea mariana*), and balsam fir (*Abies balsamea*). Temperate tree species include sugar maple (*Acer saccharum*), white pine (*Pinus strobus*), and yellow birch (*Betula alleghaniensis*). Minong was established as a national park in 1940 and gained additional protections as a congressionally designated wilderness in 1976 (99%, or 132,000 terrestrial acres designated as wilderness). Access to Minong is restricted to boat or seaplane and there is no motorized transportation on the island. Visitors who travel to Minong primarily camp, boat, or backpack. Because of its remoteness, Minong remains one of the least visited but most revisited national parks in the United States.

Existing and emerging stressors

Minong's geographic isolation has both protected the island from some modern-day direct human impacts and created unique challenges for managers. Invasive species and disease outbreaks haven't been as common on Minong as in the surrounding mainland; however, the impact of these events may be greater, considering limited opportunities for genetic rescue and plant and animal movement. For example, spruce budworm is an emerging challenge with the potential to cause widespread tree mortality in boreal forests on the island. Similarly, wildfire has the potential to remove entire vegetation communities. Natural post-disturbance succession of boreal forests is limited by a relatively small source population on the island. Furthermore, forest regeneration is greatly impacted by moose browsing activity.

Minong is considered a refugium for boreal species due to the climatic buffering effect of Lake Superior. In comparison to mainland forests, temperatures on Minong are cooler, allowing boreal and disjunct arctic-alpine plant species to persist. Nevertheless, even though climate warming may lag behind trends on the mainland, Lake Superior is one of the fastest-warming lakes in the world (GLISA 2025; O'Reilly et al. 2015) and evidence of climate change is apparent on Minong. In particular, island populations of moose and wolves are susceptible to extreme fluctuations associated with geographic isolation and changing climate. Warming air and water temperatures have reduced winter ice pack on Lake Superior, affecting the reliability of an ice bridge that historically enabled animal movement between Minong and the mainland. In 2018 and 2019, NPS managers relocated wolves from Minnesota, Michigan, and Ontario, Canada, to Minong to increase genetic diversity of island wolf populations and restore wolf-moose predator-prey relationships that have occurred on the island in recent history. Additionally, increasing temperatures, fluctuating precipitation patterns, and increasing prevalence of drought are contributing to altered wildfire behavior, decreased regeneration of sensitive plant species, and facilitated spread of invasive species. In 2021, the lightning-ignited Horne Fire burned approximately 335 acres largely within boreal forest communities and became the third largest fire recorded on the island. Initially, the fire was monitored and allowed to burn slowly until a wind event triggered rapid fire growth and suppression efforts to protect historical structures. Managers are currently investigating post-fire forest regeneration, particularly the impact of moose browse on seedling emergence and establishment.



Box 1: Location of Isle Royale National Park in the United States indicated by the purple dot (middle row, right column) and within Lake Superior. Top row, left to right, view of Tobin Harbor, northeast Minong, and spruce budworm damage on a white balsam fir (*Abies balsamea*). Middle row, left, view of the eastern boundary of the 2021 Horne Fire as of 2022. Bottom, map of Minong (largest island) and surrounding islands of the national park.

Investigate Transformation

Minong

Ecological Transformation Projections for Forest Communities on Minong

Methods

Climate Change Modeling

Daily historical (1979-2010) climate data were obtained from GridMET and future (2060) climate projections were produced from MACA downscaled climate data (Abatzoglou 2013). To capture a range of potential futures and climate change impacts, three climate models were selected to generate a suite of divergent and plausible climatic futures for Minong (Lawrence et al. 2021). By exploring a range of potential futures, managers can make adaptation decisions more robust to uncertainty and avoid surprises. Climate futures were selected based on projections of minimum winter temperature and summer precipitation amount. All three models projected increases in winter minimum temperatures by varying magnitude, however precipitation either increased, decreased, or remained similar to historical precipitation amounts. The resulting three climate futures were labeled as hot/dry, warm, and hot/wet (Table 3).

Table 3: Climate futures analyzed in this study. Climate futures were selected based on changes in minimum winter temperature and summer precipitation amount from historical (1979-2010) means to 2060. Divergent futures were generated from the three models below with their corresponding end-of-century projections.

	Climate Model	*Minimum Winter Temp ^{o}F*	*Summer Precip (inches)*
Hot/Dry	CanESM2 RCP 8.5	+12.7^{o} F	-3.2”
Warm	GFDL-ESM2M RCP 4.5	+4.6^{o} F	No significant change
Hot/Wet	MRI-CGCM3 RCP 8.5	+10.5^{o} F	+3”

Dynamic Forest Simulation Modeling: LANDIS-II

A LANDIS-II dynamic forest simulation model was used to investigate how climate change may interact with existing environmental and biological stressors to alter forest composition and structure on Minong through 2060 (mid-century). LANDIS-II is a spatial framework for investigating landscape changes as a function of vegetation change, disturbance, and management (Scheller et al. 2007). To identify key drivers of forest change, scientists consulted with NPS staff and GPLSC forestry and natural resources staff. After a site visit to Minong and several follow-up conversations, three disturbance agents were selected for future modeling: wildfire, moose browse, and forest defoliation as caused by forest pests such as spruce budworm and white satin moth. Aboveground forest biomass and forest regeneration were used as metrics to quantify the impacts of climate change and other interacting disturbances on forest communities. Forest biomass was defined as total biomass of all age cohorts whereas regeneration was represented by net regeneration among newly established cohorts, or the difference between recruitment and mortality caused by moose browse for all young trees at a unique site. To investigate whether boreal forest species may be more vulnerable to climate change and compounding disturbances, we organized our results by boreal and temperate forest species found on Minong (Table 4).

Table 4: Tree species analyzed in a study of forest composition change of boreal and temperate forest types on the island of Minong, Isle Royale National Park, USA.

Species Code	Species	Common Name	Forest Type
ABBA	*Abies balsamea*	balsam fir	boreal
ALIN2	*Alnus incana*	gray alder	boreal
BEPA	*Betula papyrifera*	paper birch	boreal
FRNI	*Fraxinus nigra*	black ash	boreal
LALA	*Larix laricina*	larch	boreal
PIGL	*Picea glauca*	white spruce	boreal
PIMA	*Picea mariana*	black spruce	boreal
POGR4	*Populus grandidentata*	bigtooth aspen	boreal
POTR5	*Populus tremuloides*	quaking aspen	boreal
SODE3	*Sorbus decora*	mountain ash	boreal
THOC2	*Thuja occidentalis*	northern white cedar	boreal
ACRU	*Acer rubrum*	red maple	temperate
ACSA3	*Acer saccharum*	sugar maple	temperate
ACSP2	*Acer spicatum*	mountain maple	temperate
BEAL2	*Betula alleghaniensis*	yellow birch	temperate
CRDO2	*Crataegus douglasii*	black hawthorn	temperate
PIBA2	*Pinus banksiana*	jack pine	temperate
PIRE	*Pinus resinosa*	red pine	temperate
PIST	*Pinus strobus*	Eastern white pine	temperate
POBA2	*Populus balsamifera*	balsam poplar	temperate
PRVI	*Prunus virginiana*	chokecherry	temperate
QURU	*Quercus rubra*	northern red oak	temperate

Management Alternatives

To better understand how management activity may contribute to forest resilience, or the ability of a forest to absorb and recover from disturbance, two management alternatives were applied to the modeling environment. The first alternative, a "business-as-usual" approach, included current management strategies for wildfire management and moose population management on Minong. Wildfire strategies included wildfire suppression around historical structures and suppression of human-ignited fire (e.g., escaped campfire). To investigate the influence of moose population management, models simulated moose browse intensity as a function of wolf predation at three levels (high, moderate, and low). The second alternative, a "hands-off" alternative, allowed natural processes to occur without human interference. No wildfire or moose management occurred in this version of the model. Moose browse was held constant around moderate levels of browse intensity. For both alternatives, impacts of forest pests were allowed to occur autonomously as an independent agent of chaos.

Results

Model and Prediction Uncertainty

The following scenarios are presented as plausible ecological trajectories generated with the best available data and knowledge. Some uncertainty about direct and indirect causal relationships persists, however, and therefore continued advances in our understanding of climate change trends and resultant ecological impacts are likely to support further refinement. Furthermore, several ecological scenarios may emerge from a single climate future (Clark-Wolf et al. 2025). The scenarios presented here are meant to be used as reference points for further refinement as new knowledge and data become available.

Forest Aboveground Biomass and Regeneration

Vegetation change trajectories (scenarios) differed largely in terms of the magnitude of ecological change rather than the direction (increase vs. decrease) (Appendix A). Under all climate futures, overall aboveground forest biomass was projected to increase to 2040, with increases in the Hot/Dry trajectory of 10-11% (depending on level of moose browse), in the Hot/Wet of 6-10%, and in the Warm trajectory of 7-10% (Figure 2). Thereafter, forest biomass is projected to decrease in all trajectories, with 2060 values in the Hot/Dry trajectory remaining 2-5% above 2020 values, in the Warm trajectory being equal to or slightly less than 2020 values, and in the Hot/Wet trajectory spanning the range defined by the other two. At the species level, six of the eleven boreal species experienced increased biomass regardless of climate future or moose browse level. By contrast, three species (quaking aspen [*Populus tremuloides*], mountain ash [*Sorbus decora*], and balsam fir [*Abies balsamea*]) experienced decreases to well below 2020 levels, regardless of climate future or moose browse level, and two (Bigtooth aspen

[*Populus grandidentata*] and northern white cedar [*Thuja occidentalis*]) experienced increases if moose browse level were low but otherwise experienced decreases below 2020 levels.

Projected biomass trends for temperate species were also mixed. For three species, sugar maple (*Acer saccharum*), jack pine (*Acer saccharum*), and eastern white pine (*Pinus strobus*), biomass was projected to consistently increase. By contrast, for four species, mountain maple (*Acer spicatum*), yellow birch (*Betula alleghaniensis*), red pine (*Pinus resinosa*), and balsam poplar (*Populus balsamifera*), biomass was projected to consistently decrease.

Similarity in direction of change among climate futures was true overall for trends in biomass over time, however, there were a few examples where forest regeneration differed among climate futures. For example, for three boreal species, black ash (*Fraxinus nigra*), larch (*Larix laricina*), and gray alder (*Alnus incana*), regeneration was projected to increase under the hot/wet and warm futures but decrease under the hot/dry future. Similarly, for boreal species bigtooth aspen (*Populus grandidentata*) and mountain ash (*Sorbus decora*), regeneration is expected to increase under the hot/wet and warm futures, but plateau under the hot/dry future. For temperate species balsam poplar (*Populus balsamifera*), jack pine (*Pinus banksiana*), and northern red oak (*Quercus rubra*), regeneration was also projected to increase under the hot/wet and warm futures, but either decrease or plateau under the hot/dry future. By contrast, for boreal species white spruce (*Picea glauca*) and black spruce (*Picea mariana*) regeneration decreased under both the hot/dry and hot/wet futures but increased under the warm future. Overall, the hot/dry future was most associated with either decreasing or plateauing regeneration among both boreal and temperate species.

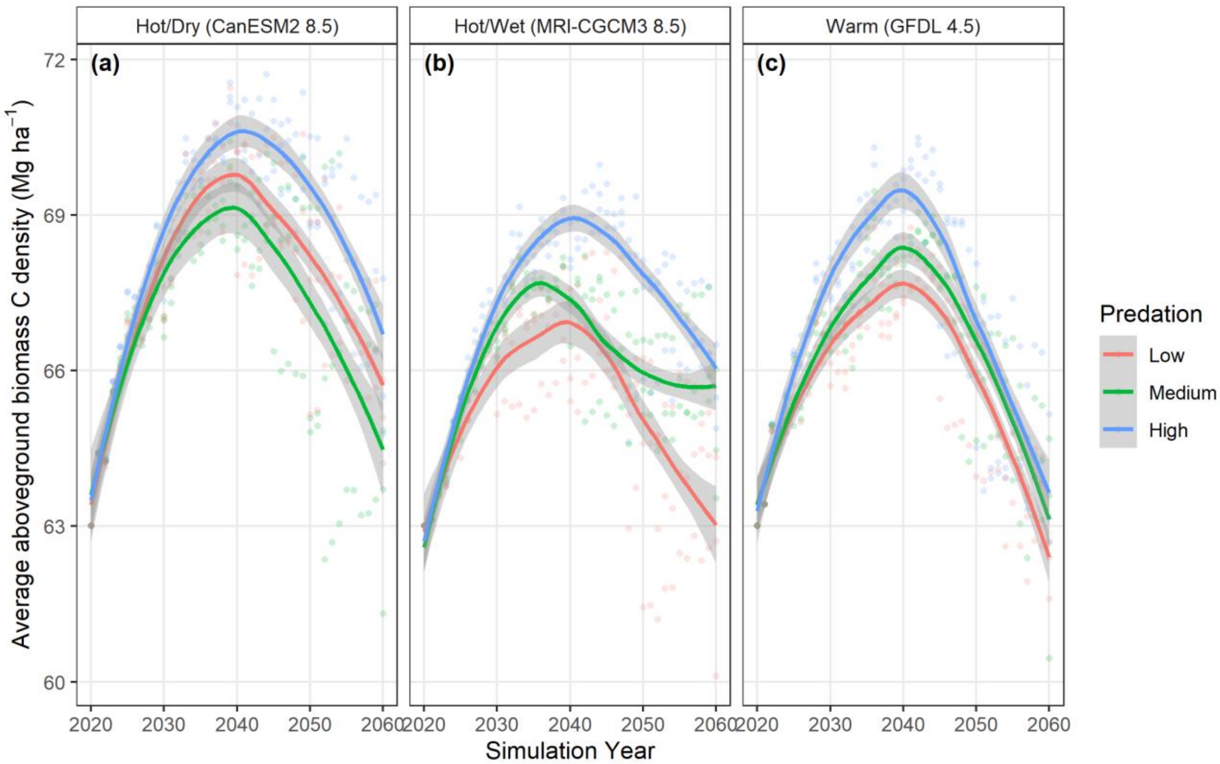


Figure 2: Projected trends in average aboveground vegetation biomass across Minong, Isle Royale National Park, USA projected to 2060 for three climate futures (Hot/Dry, Hot/Wet, Warm) and for three levels of intensity of moose browse as moderated by predation pressure. Individual lines represent predation pressure on moose populations (high predation=low moose density; medium predation=moderate moose density; low predation=high moose density).

Moose Populations

Pertinent to forest change, moose population density and carrying capacity were also impacted by climate change. Trends in both population density (# moose/km^2) and carrying capacity largely declined over time among climate futures (Figure 3). Nevertheless, unlike in the hot/dry future which experienced overall negative trends, carrying capacity for moose in the hot/wet and warm futures initially declined to 2050 then increased in the last decade to 2060. For all climate futures, population density displayed a negative trend. Under the hot/dry future, moose population density was lower overall than in the hot/wet and warm futures and population density more closely approached carrying capacity.

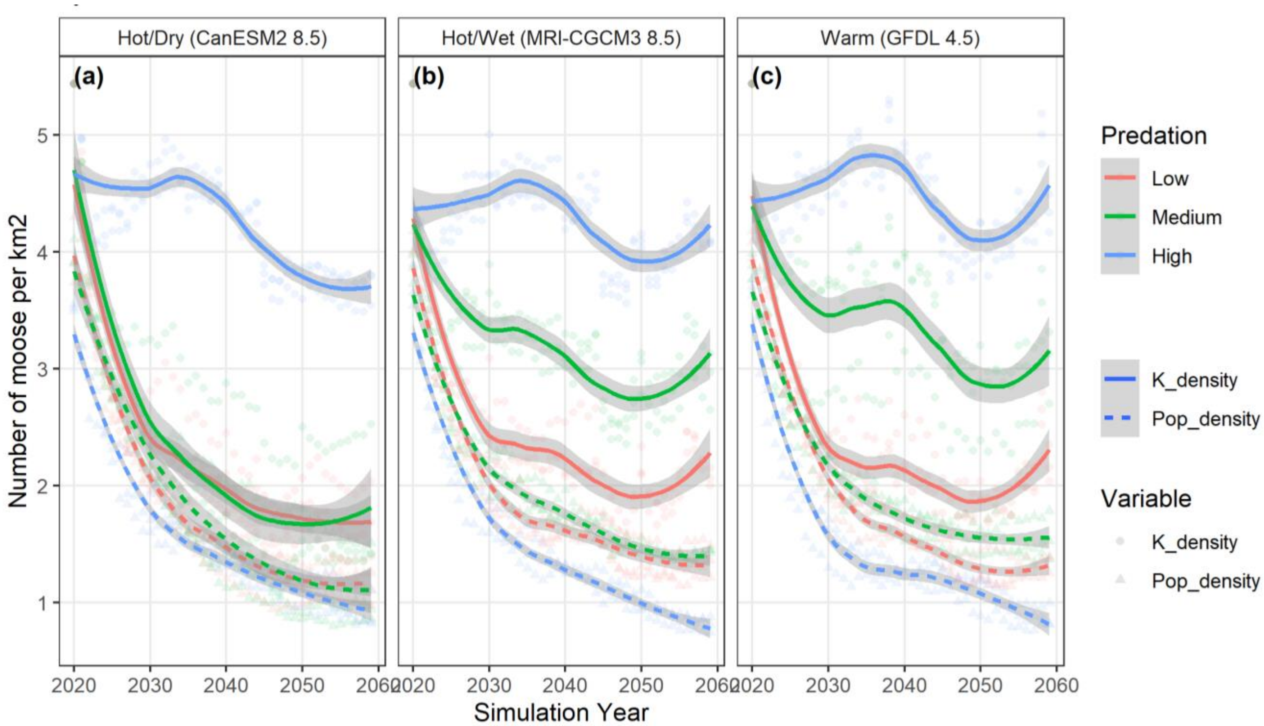


Figure 3: Trends in moose population density (Pop_density) and carrying capacity (K_density) on Minong, Isle Royale National Park, USA projected to 2060 for three climate change futures (Hot/Dry, Hot/Wet, Warm) and for three levels representing predation pressure. Individual lines represent predation pressure on moose populations (high predation=low moose density; medium predation=moderate moose density; low predation=high moose density).

Wildfire

Trends in total area burned as well as proportion of area burned at high intensity varied among climate futures (Figure 4). Total area burned was similar for the hot/dry and warm futures but increased slightly by mid-century for the hot/wet future. Proportion of area burned at high intensity was greater in the hot/dry and hot/wet futures than in the warm future and tended to increase over time. High-intensity fire was defined as any fire that was likely to kill all vegetation and burn organic matter (difference normalized burn ratio [dNBR]>500).

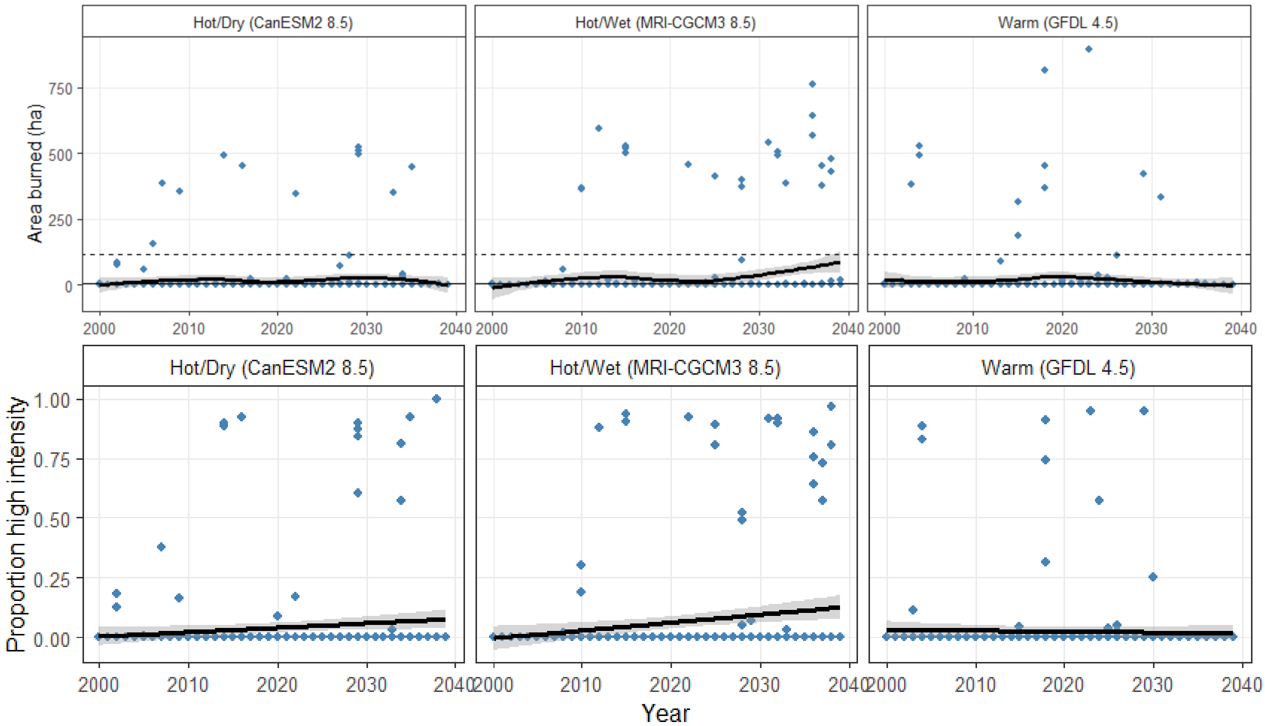


Figure 4: Trends (black curve with gray shading) in total area burned (ha) (upper panel) and proportion of area burned at high intensity (lower panel) for Minong, Isle Royale National Park, USA by 2040. Each datapoint (i.e., blue diamond) represents a wildfire. For graphs in the upper panel, the horizontal dotted line that crosses the y axis represents the mean annual historical area burned, using 1900-1990 as the reference period, including a large 1936 wildfire while the horizontal solid line that crosses the y axis just above the value of zero is the mean historical area burned excluding the 1936 fire.

Forest Pests

Modeling did not reveal any clear linkages between climate futures and forest damage caused by forest pests (Figure 5). Overall, spruce budworm had the largest impact on tree mortality among all climate change futures. Spruce budworm mortality was particularly prevalent for balsam fir (*Abies balsamea*). Other defoliators, such as white satin moth and tent caterpillars, caused consistent low levels of mortality that showed no increasing or decreasing trend through time.

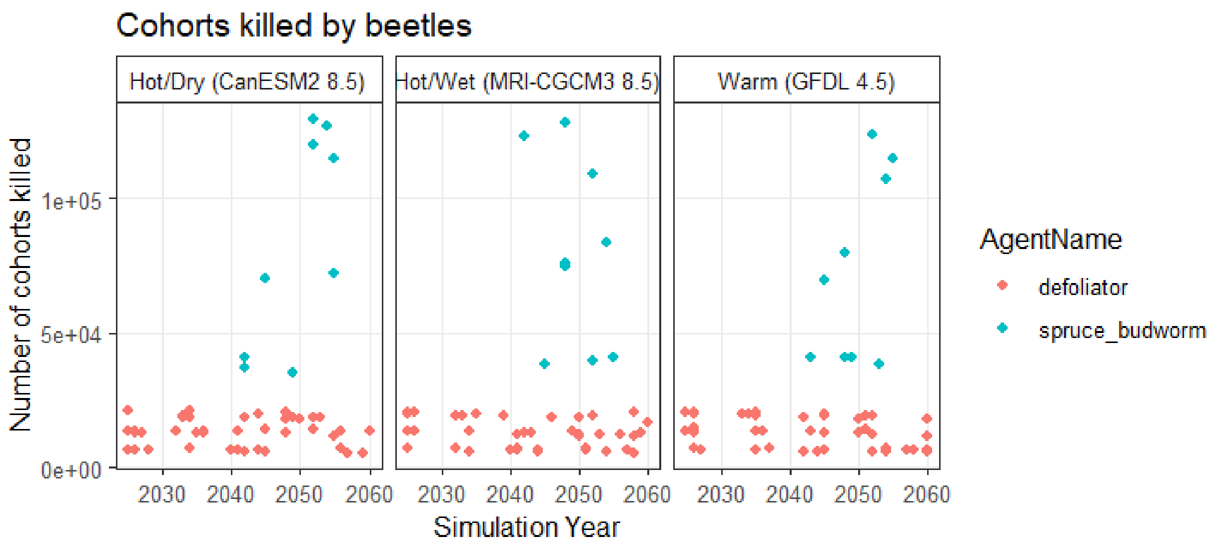


Figure 5: Number of forest cohorts (groups of trees categorized by age and species) killed by spruce budworm and other forest defoliators (white satin moth, and others) from 2020-2060 on Minong, Isle Royale National Park, USA. Due to currently low occurrence of spruce budworm on Minong, models predicted that populations of this defoliator wouldn't begin to significantly damage forest cohorts until 2040.

Management Alternatives

Whether to manage wildfire and moose browse intensity defined our two management alternatives: "business-as-usual" and "hands-off" (Appendix A). Continued suppression of human-ignited fire and of all fires around historical structures (e.g. the "business-as-usual" alternative) had negligible effects on changes in either forest biomass or regeneration when compared to strategies where wildfire was not suppressed (e.g. the "hands-off" alternative). By contrast, modifying moose browse intensity contributed to slight differences in magnitude of forest change over time, although direction of change was unaffected. High moose browse intensity (low predation pressure) was associated with decreased biomass and regeneration of key boreal forest species such as balsam fir (*Abies balsamea*), bigtooth aspen (*Populus grandidenta*), and northern white cedar (*Thuja occidentalis*); however, moose browse seemed to have little effect on other boreal species such as white spruce (*Picea glauca*) and mixed results for paper birch (*Betula papyrifera*). Temperate deciduous species such as sugar maple (*Acer saccharum*) and yellow birch (*Betula alleghaniensis*) were also negatively affected by increasing intensity of moose browse. By contrast, increasing moose browse intensity was associated with greater aboveground biomass of red pine (*Pinus resinosa*), although there seemed to be negligible differences of browse intensity on regeneration (Appendix A).

Ecological Transformation

Replacement of Boreal Forest by Temperate Forest

Although trends in aboveground biomass for boreal species were mixed (as described above in the Forest Aboveground Biomass and Regeneration section), spatial analysis demonstrates clear patterns of biomass change through 2060 in boreal forest as a whole among climate futures and management alternatives (Figure 6A). These changes were similar under the "business-as-usual" and "hands-off" alternatives. Overall, boreal forest biomass was projected to decrease on Minong, with decreases most apparent along ridges where organic matter is shallow and sites are drier. Boreal species were projected, however, to make some gains in wetter, lowland areas where conditions may remain or become more favorable.

Temperate forest species, in contrast, were projected to increase in biomass, particularly following disturbances such as wildfire (Figure 6B). Increase in biomass of temperate species often overlapped with decreases in biomass of boreal species, indicating an ecological transformation. Temperate species were projected to experience the greatest decrease in biomass within the southwest region of Minong.

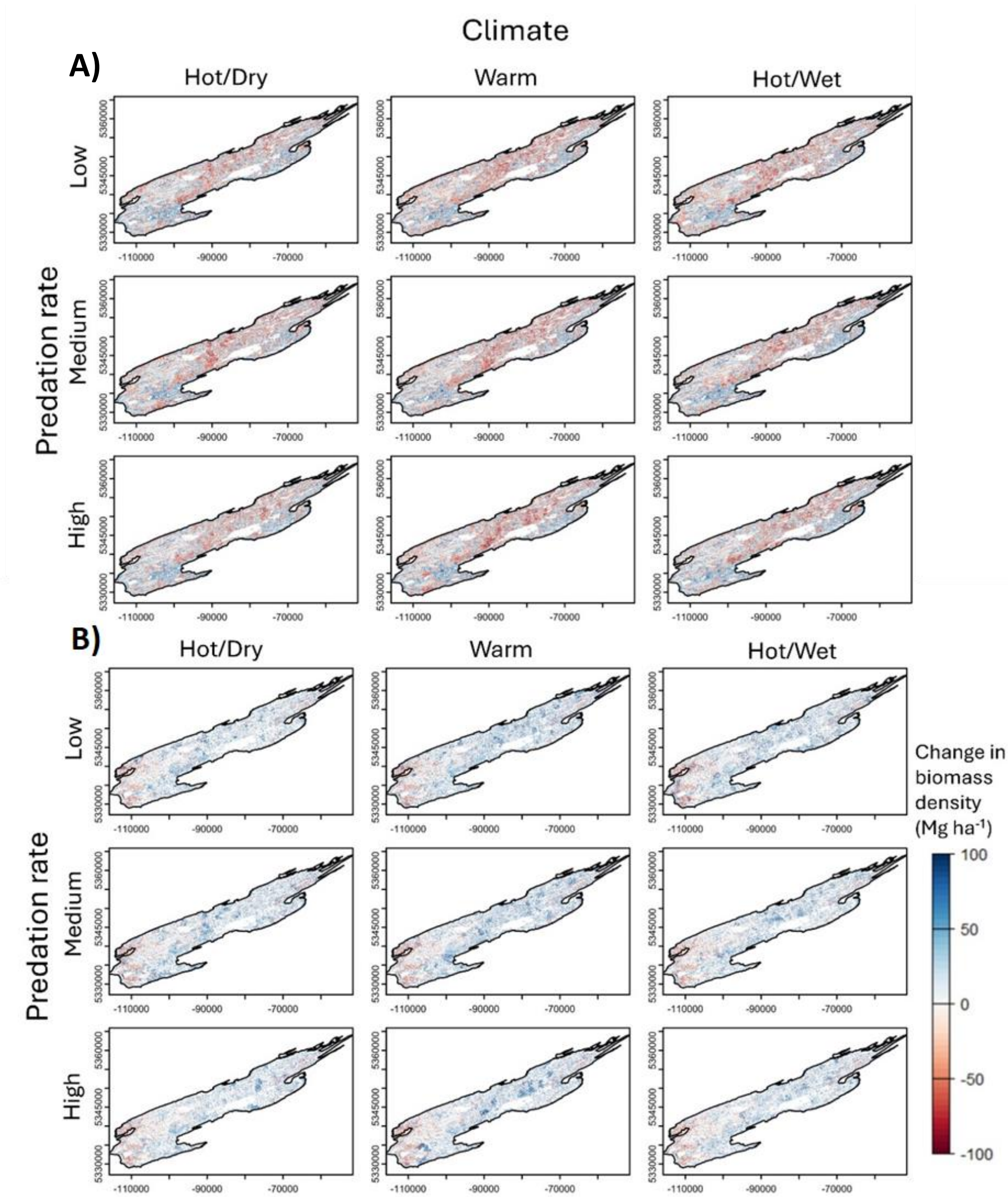


Figure 6: Change in forest biomass density (Mg ha^{-1}) of A) boreal forest and, B) temperate forest, on Minong, Isle Royale National Park, from 2020-2060 for three climate futures (hot/dry, warm, hot/wet) and three levels of predation pressure on moose populations. Results represent a "business-as-usual" management scenario that includes fire suppression.

Transformation of Forest to Other Vegetation Community Types

Overall, forest cover was projected to decrease in several areas of the island by 2060 (Figure 7). Areas where forest cover is expected to make gains included wetter, low-lying areas of Minong. Ridgelines and the southwest region of Minong appeared to be particularly vulnerable to forest loss. Decreases in forest cover largely occurred due to fires or windthrow events, where a loss of overstory cover may not have recovered by the end of the model run. Projected forest loss may be temporary as forests regenerate following disturbance or, alternatively, gaps in forest cover may persist into the future. If forest gaps persist and accumulate over time, large-scale transformation of forest to other vegetation community types, such as grassland or shrubland, may occur.

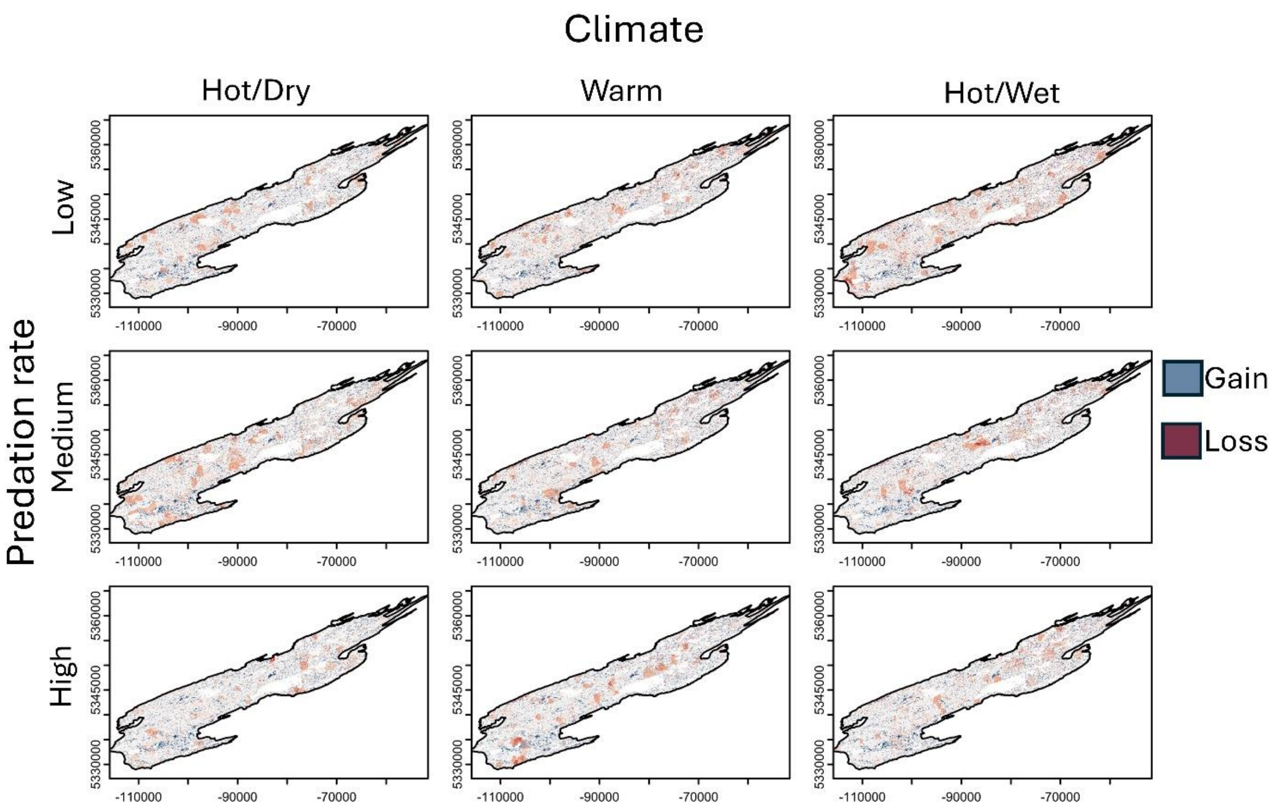


Figure 7: Overall change in forest cover on Minong, Isle Royale National Park, from 2020-2060 for three climate futures (hot/dry, warm, hot/wet) and three levels of predation pressure on moose populations. Results represent a "business-as-usual" management scenario that includes fire suppression. Forest cover was defined as sites with a leaf area index ≥ 3.

Conclusions

Forest communities on Minong are changing in ways that could have far-reaching impacts on wildlife, recreation experience, and cultural heritage and practices. Current management strategies that involve suppression of human-ignited fire and control of moose browse intensity may not be sufficient to alter the direction of change occurring within forests. Managing moose populations may decrease the magnitude of change over time, however, wildfire and climate change will remain the two largest drivers of shifts in the composition and structure of forest communities.

Tree species had variable responses to climate change over time. For many species, initial warming associated with climate change led to increased biomass and regeneration, however, the benefits of warming may not supersede the impacts from increasing drought and rates of evapotranspiration. Dry forest conditions can lead to increased prevalence and intensity of wildfire and reduced regeneration for some tree species. For boreal species, high-intensity wildfire coupled with heavy moose browse and defoliation by forest pests may lead to regeneration failure, particularly along ridgelines and drier sites on the island. These findings concur with previous studies of forest change on Minong (De Jager et al. 2020; Fisichelli et al. 2013).

Loss of boreal species may coincide with increases in temperate forest species, resulting in forest type conversion. However, in some areas, forest cover may be lost altogether, resulting in a transformation from forest to another vegetation cover type, such as shrubland or grassland. Models used in this analysis only simulated forest change through 2060 and it is unclear whether these transformations would persist or if boreal forest would make a recovery following wildfire.

These preliminary results should be considered with caution. Climate change and simulation modeling involves a high degree of uncertainty. We attempted to reduce uncertainty by using the best available data and research to inform model parameters and we worked with irreducible uncertainty by creating a suite of climate futures to capture a range of potential futures for Minong. Nevertheless, these results should be used as a guide rather than a crystal ball to inform management strategies and to design future research projects that can help improve model performance over time.

Manager Perceptions of Climate Change and Feasibility of Response Actions

To learn how NPS and GPLSC staff are experiencing climate change and ecological transformation, as well as their perceptions of response options, we conducted seven semi-structured interviews. A semi-structured interview approach uses the same list of questions (or interview guide) for all participants and allows room for exploration into unique topics relevant to each participant. Therefore, some participants were asked additional and unique questions based on their positions and responses. This approach ensures comparable results across participants while also allowing for unique insights and freedom of response (Kvale & Brinkmann 2009). Interviews were conducted with key NPS and GPLSC staff. In particular, we were interested in understanding perceptions of (1) how climate change is affecting areas on Minong and on the Grand Portage Band Reservation, and (2) feasibility of management actions to support conservation of boreal forest communities, including constraints and opportunities for climate change adaptive actions on Minong.

Minong is within the traditional homelands of the GPLSC and considered part of their unceded territory. Both NPS and Tribal staff recognized the Tribe would like to maintain its connection to Minong, not only for cultural preservation, but also because the island may be less impacted by climate change. Nevertheless, some of the Tribal natural resources staff that we interviewed had not traveled to Minong for several years. We therefore allowed these interviewees to address questions relevant to their experience managing similar forested systems on Tribal land in northern Minnesota, USA. Out of seven total interviews, five were conducted virtually and two were conducted in-person on Minong. All interviews were conducted between June 22, 2023, and December 18, 2024, and lasted an average of 52 minutes. Six interviews were recorded and transcribed verbatim. One interview was not recorded, but detailed notes were taken. Identities were removed from transcripts to ensure participant confidentiality. All deidentified transcripts were uploaded into NVivo—a qualitative data analysis software, which helps researchers organize data. Qualitative thematic analysis was conducted with open or inductive coding in which the researcher identifies distinct concepts and themes for data categorization (Williams & Moser 2019). These concepts and themes were then considered together as they relate to larger trends across the data (Braun & Clark 2012). See Appendix B for interview quotes that pertain to each theme.

Perceived effects of climate change on Minong and Tribal trust lands

NPS managers noted that warming, drought, forest pests, and changing wildfire regimes were impacting boreal forest persistence on Minong. One NPS manager shared that the most sensitive species to warming were balsam fir, white spruce, and aspen, or any other species existing at its southernmost extent on Minong. Although managers felt that future climate might be suitable for temperate species, they acknowledged these species may not do as well as they might on the mainland due to the shallow soil and bedrock on Minong. Furthermore, managers indicated that post-disturbance forest recruitment and recovery may be negatively impacted by moose herbivory and insect defoliators.

In addition to changing forest conditions on Minong, NPS managers also noted warming lake temperatures in Lake Superior and inland lakes, including lack of winter ice on Lake Superior. One NPS manager noted that increasing lake temperatures in Lake Superior were facilitating colonization by invasive aquatic mussels. These mussels threaten archeological resources (i.e., shipwrecks) and park docks in shallower waters. One NPS manager, an archeologist, noted that he was having to spend more time manually plucking invasive mussels off docks and shipwrecks. Managers also discussed how increasing inland lake temperatures are decreasing habitat for coldwater fish species and are causing harmful algal blooms. Managers have also observed stronger winds on Minong, which were attributed to greater potential for larger and higher-severity wildfires in summer months. Additionally, larger, wind-driven waves were also perceived to threaten nearshore archeological sites in the winter.

All NPS managers stated that climate change was greatly impacting both the scope of their work and day-to-day activities. In particular, increasing wildfire severity on Minong was a notable theme among interviewees. The current fire management strategy on Minong is limited to suppression, wherein all human-caused fires are suppressed and natural-caused fires are suppressed if they threaten historical structures or human life. Nevertheless, most managers shared that increased risk and occurrence of high-severity fire is making managing naturally caused fire more complicated. NPS managers discussed potential dangers to personnel and visitors in the event of high-severity fire and the concern over decreased post-fire boreal forest recruitment.

Despite emerging challenges for forests on Minong, one Tribal staff member described Minong as a potential "climate change mitigation strategy" because moose, birch, medicines, and other culturally significant and subsistence species may persist on the island longer than they do on the mainland. Indeed, many NPS and Tribal managers felt that Lake Superior acted as a buffer against several impacts of climate change for Minong and that change on the island was not happening as quickly or to the same degree as change on the mainland. On Tribal trust lands, GPLSC managers have already observed several implications of a warming climate, including warming inland lakes, lack of ice on Lake Superior, increased prevalence of winter ticks (which are increasingly fatal for moose), increased deer survival, and decreased ground freezing. GPLSC managers stated that warming of inland lakes has also resulted in the extirpation of coldwater obligate brook trout from an inland lake on Tribal trust lands. Due to warmer winter temperatures, managers noted that the ground on Tribal trust lands was not freezing as deeply, which constrains timber harvest season, Tribal member access, and forage for moose. In addition to decreased forage, managers discussed several ways in which the warming climate was associated with declining moose populations. First, whitetail deer populations have been shifting north due to increasing temperatures and decreasing snow depth, bringing with them a lethal parasite for moose: brainworm. In addition to brainworm, deer are attracting more predators such as bear and wolves who prey intensely on moose calves. Finally, in addition to parasite and predator-driven moose decline, one manager felt that warming temperatures are slowly changing the species moose rely on for forage. In contrast, moose on Minong are not currently threatened by brainworm because there are no deer on the island. Additionally, although wolves were recently reintroduced, moose populations on the island remain robust.

In addition to a general warming trend on Tribal trust lands, GPLSC staff noticed more extreme weather events, changes to fire season such as widely fluctuating fire risk with summer precipitation, increased wind, and changing climate regimes in lakeside and upland regions. Managers associated these changes with damage to infrastructure (e.g., roads and bridges), damage to rice lakes, negative impacts on trout populations, and reduced Tribal member access to subsistence hunting and medicine gathering. Like NPS managers on Minong, Tribal trust land managers shared that extreme weather is increasingly impacting their work. Primarily, managers said that they have needed to spend more time on infrastructure restoration, needed to implement more fire restrictions, and had to change their schedules in response to fire danger—working later in the day.

The GPLSC has a climate change adaptation plan to ensure natural resources staff and the Grand Portage Band consider climate change in all their management responsibilities. GPLSC staff shared that ensuring Tribal member access to subsistence hunting (primarily moose) and gathering of culturally important species like paper birch and medicines is one of the most important aspects of their jobs. Climate change directly and indirectly impacts these species and practices, and Trust lands staff have been adapting their approaches to ensure subsistence and cultural preservation into the future. For example, when an inland lake became unlivable for brook trout, biologists, with approval from Tribal council, began stocking the lake with yellow perch and walleye, which are more tolerant of warmer water temperatures (see Moore & Isaac 2026 for more information). Foresters shared that they are planting more species that are better adapted to emerging climatic conditions such as white pine and sugar maple and are experimenting with assisted migration by growing out and planting seedlings from more southerly seed zones. Additionally, foresters noted that they are focusing on increasing forest resilience through planting diverse species at lower densities, and by thinning and burning existing stands. To resist depletion of moose populations, foresters and biologists are working to enhance moose forage and to manage deer and bear populations. So far, GPLSC staff felt all these efforts were successful.

Feasibility of management actions to support boreal forest conservation in wilderness

Constraints on climate adaptation on Minong and Tribal trust lands

NPS managers discussed Minong's remoteness as a physical constraint that makes addressing climate change challenging, particularly as it relates to weather and climate projections and wildfire management. Several NPS managers shared that due to its location in Lake Superior, Minong has different weather and climatic conditions from the mainland. Because climate models are largely based off mainland data, forecasting weather and anticipating localized effects of projected climate change on Minong is difficult. Additionally, there is little access to internet and weather forecasts, which makes wildfire management particularly challenging. Lacking accurate weather forecasts has been particularly challenging in recent years as wildfires have intensified. In addition to challenges with climate models and weather forecasts, the remoteness of the island makes it difficult to mobilize staff and resources in the event of a fire.

Few park staff have the necessary certifications for managing wildfires, which necessitates bringing in regional and interagency fire resources. In a year with high national preparedness levels, this can mean these shared resources will need to suppress wildfires rather than manage fires for resource benefits when possible.

NPS managers and GPLSC staff shared several institutional constraints that make addressing climate change difficult on the island and on the mainland. Lack of staff and funding capacity was a pervasive constraint for Tribal and NPS managers. One Tribal trust land manager shared that recruiting staff was difficult and being understaffed impacts the Tribe's ability to implement projects even when they get supplemental outside funding. Tribal staff also indicated that managing for forest resilience is expensive and can be especially difficult to fund when timber markets are depressed. NPS staff shared that Minong was particularly understaffed compared to other national parks. In a busy national park, low staff capacity makes it difficult to consider challenges like climate change and plan proactively. GPLSC staff felt the island's remoteness and need for federally mandated processes may constrain their ability to implement desired projects. In addition to capacity and process constraints, some NPS staff felt constrained in their ability to respond to climate change impacts because they were not sure what management activities would be appropriate within wilderness. For example, one NPS manager shared that they felt it would be difficult to plant tree seedlings or seeds from warmer seed zones because the park does not currently have a framework for planting with off-island genetics. This lack of clarity has impacted their decision to implement more active management, including wildfire management.

Although wildfire suppression is implemented under the current wildfire management strategy for Minong, prescribed fire is not currently used. In addition to lack of clarity surrounding allowable actions under the Wilderness Act, GPLSC staff discussed several physical and institutional constraints on actions such as prescribed fire or cultural burning on Minong. First, they shared that finding good weather windows for burning is extremely challenging and suggested this may be even more challenging to predict for the island than for the mainland. Second, access to resources (i.e., personnel, suppression resources, drip torches) is often limited and these resources need to be shared with adjacent lands. Even when conditions are favorable for burning on the mainland, staff and resources from other regions still must reserve resources in the event of a wildfire. GPLSC staff also recognized that due to Minong's remoteness, it may be particularly difficult to mobilize staff and resources to restore cultural burning on the island. Finally, even if an appropriate burn window occurs when there are resources available, wind off Lake Superior often brings humidity that can slow or halt prescribed fire efforts and Tribal staff felt this phenomenon may be particularly challenging when burning on Minong.

Opportunities for climate adaptation on Minong and Tribal trust lands

Despite numerous constraints and challenges, NPS and GPLSC staff identified several opportunities for climate adaptation in wilderness on Minong. For example, managers shared that continuing to allow lightning-ignited fires to burn could make boreal forests more resilient to climate change. To encourage recovery and persistence of boreal forest species on Minong, NPS staff also felt that reseeding in fire scars and/or underplanting balsam fir could be feasible future actions. Additionally, NPS staff felt that conducting prescribed burns in collaboration with the GPLSC would be beneficial if integrated into their fire management plan.

GPLSC staff identified unique opportunities to address climate change challenges on Minong through federal-Tribal co-stewardship. One Tribal trust land manager felt that co-stewardship could help justify and increase capacity for land management activities. Furthermore, GPLSC staff felt they could apply lessons learned on Tribal trust lands to benefit forest management strategies on Minong. Tribal staff recognized that they are relatively nimble as compared to the NPS, including their ability to obtain approval for projects. In comparison, the NPS requires fulfillment of several legal processes such as National Environmental Policy Act analyses and public comment periods before plans can be approved and implemented. Tribal staff felt that their nimbleness could facilitate co-stewardship activities on Minong.

Although Tribal staff weren't sure it was necessary, one staff member felt like a formalized co-stewardship agreement with the park could be beneficial. They reflected that an agreement would provide a formal structure with mechanisms to guide the co-stewardship process, which could be especially useful in cases where the park and the Tribe disagree. Additionally, having a formal agreement could serve as justification for funding allocations and for management actions.

Apply the RAD Framework to Climate-Informed Adaptation Planning in Wilderness

Minong

Learning Objectives

A 2-day, in-person workshop was conducted to support overarching project goals to inform and evaluate the decision space when responding to ecological transformation using the RAD framework and to support climate-informed adaption planning in wilderness. During the workshop, participants followed a generalized adaptation planning process that applied the RAD framework to generate and evaluate decision alternatives for forest communities on Minong under a changing climate. The workshop was structured around four learning objectives:

1) Orient the Minong case study in the broader challenge of wilderness management in an era of climate change
2) Identify desired conditions surrounding the focal ecological transformation that reflects all perspectives
3) Understand the utility of RAD as a tool for responding to ecological transformation in wilderness
4) Develop a feasible and repeatable workflow to evaluate RAD decision alternatives

Each learning objective was achieved through a combination of scientific inquiry (described above), facilitated discussion, and small group activities. Both biological and social science investigations were leveraged to better understand how ecological conditions may change on Minong and how land stewards and their partners perceive this change and their ability to prepare for or respond to climate change-driven transformation. Preliminary and final results of science investigations were shared with workshop participants during the workshop to characterize potential ecological transformation for forest communities and to encourage further discussion concerning real and perceived constraints and opportunities to conserve boreal forest ecosystems. Facilitated small-group activities and discussion encouraged co-production of ideas and decision alternatives that were examined further with additional decision-support tools.

Workshop Participants

Workshop participants worked for or represented the Grand Portage Band of Lake Superior Chippewa (GPLSC), the Grand Portage National Monument (GPLSC-NPS), and Isle Royale

National Park (NPS). Staff biologists, ecologists, foresters, and leadership were included. In total, nine individuals attended the workshop.

Applying the RAD Framework

The RAD framework is a tool meant to be used during a planning process to support decision making in an era of ecological transformation under climate change (Miller et al. 2025; Schuurman et al. 2025). Using the RAD framework, land stewards can generate a broad range of decision alternatives to deliberately intervene or not intervene to address climate change threats (Crausbay et al. 2022; Schuurman et al. 2022). During the workshop, the RAD framework was applied in a generalized planning process based on adaptive management (Figure 8). Adaptive management is an iterative, structured decision-making process used to clarify and address uncertainty associated with implementing divergent management strategies (Johnson 1999). Incorporating RAD into an adaptive management process is consistent with previous efforts by Crausbay et al. (2022) and Lynch et al. (2022).

In a rapidly changing landscape where information is limited and the future is uncertain, adaptive management helps land stewards move forward by incorporating learning into decision making (McFadden et al. 2011). By critically evaluating RAD decision alternatives and monitoring the successes and shortcomings of decisions to meet desired conditions, knowledge is generated along each revolution of the adaptive management wheel. During the workshop, we sought to complete the first five stages (out of seven) of an iterative adaptive management approach (Figure 8): 1) Clarify observed climate change threats and persistent ecological stressors, 2) Identify values and desired conditions, 3) Clarify potential ecological transformation(s) that threaten values and desired conditions, 4) Generate a suite of decision alternatives to address transformation using the RAD framework, and 5) Evaluate the potential social-ecological consequences of choosing to resist, accept, or direct perceived climate change-driven changes. Subsequent stages of adaptive management, including implementing a decision alternative(s) and monitoring action effectiveness, are next steps to be completed beyond the workshop.

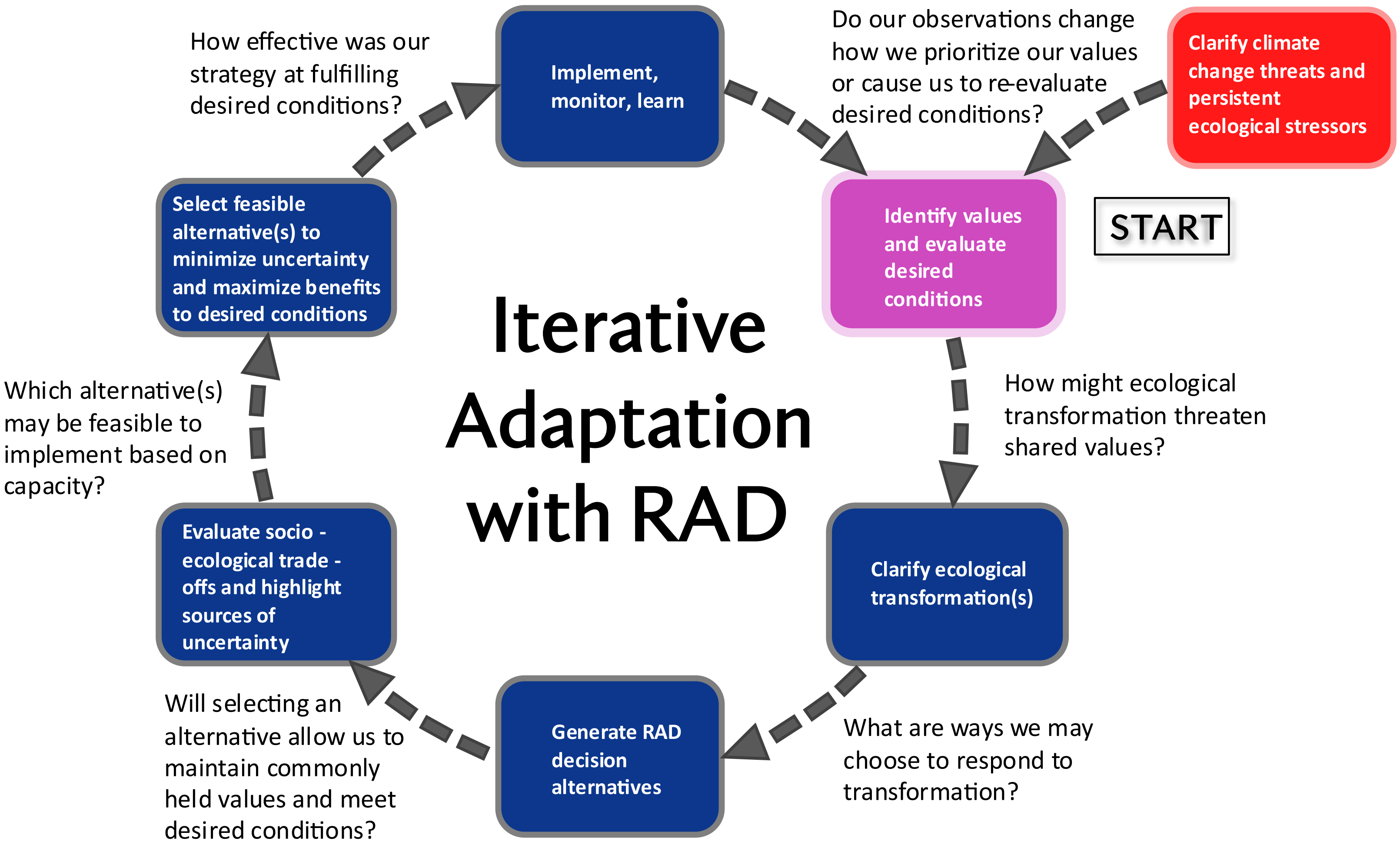


Figure 8: Iterative planning process using the resist-accept-direct (RAD) framework as a tool for climate-informed adaptation for federally designated wilderness.

Learning Objective 1: Orient Minong in the Broader Challenge of Wilderness Management in an Era of Climate Change

To orient workshop participants to the broader challenge of managing wilderness in an era of climate change, ALWRI scientists discussed how specific challenges faced by forest communities on Minong represent a wicked problem. Facilitators identified existing and anticipated ecological stressors that may contribute to ecological transformation and shared preliminary results from the semi-structured interviews described above to summarize how managers perceive the feasibility of implementing actions to respond to transformation. Since not all workshop attendees participated in an interview or work on Minong, sharing this information helped lay a foundation of shared knowledge about conditions on Minong and how they relate to national-level challenges.

The Wicked Problem Statement: Minong

On Minong, natural and human-caused disturbances compounded by climate change are transforming boreal forest communities. Loss of boreal forest may impact important biocultural relationships and alter the visitor experience on the island. Although Minong's position within Lake Superior has buffered it from the effects of climate change, the geographic isolation of Minong also makes it difficult for land stewards to respond to transformation threats such as wildfire. Additionally, Minong's isolation limits opportunities for forest establishment and recovery post-disturbance. Proactive management to address emerging climate change-driven challenges is further complicated by complex policy stipulations under the 1964 Wilderness Act. Although active management intervention, such as prescribed fire, may be useful in addressing ecological transformation, direct human manipulation of the landscape is highly scrutinized under the Wilderness Act. To conserve boreal forest and key biocultural relationships under climate change while also upholding the intent of the Wilderness Act, land stewards are tasked with identifying and balancing multi-faceted trade-offs involving impacts to wilderness character, social and ecological values, and real and perceived institutional constraints.

Learning Objective 2: Identify Desired Conditions Surrounding the Focal Ecological Transformation that Reflects all Perspectives

How individuals perceive and understand ecological transformation and contribute to a decision space is influenced by unique life experiences and values. Several internal and external factors inform individual perspectives and values including personal worldviews, cultural norms and traditions, and institutional demands or constraints (Clifford et al. 2022). Desired conditions in place-based adaptation planning may differ substantially among participants involved in planning efforts (Stern et al. 2023). Discussing solutions to climate change-driven ecological transformation can therefore become contentious when someone's values are impacted by proposed management actions or inaction. By engaging with and illuminating the multi-faceted values of impacted stakeholders and rightsholders, land stewards can build a decision space that is inclusive of the diverse perspectives of affected groups and increase transparency in decision making. Additionally, new vulnerabilities and opportunities may emerge that may strengthen strategic planning and generate new decision alternatives that were not previously considered (O'Brien et al. 2024). Such co-production efforts can accelerate knowledge transfer and promote sustained interest and support for continued planning as environmental conditions change and new threats emerge (Stern et al. 2023). With climate change-driven transformation, achieving or maintaining previously desired conditions may no longer be feasible, or prioritization of values or desired conditions may shift. Appropriately communicating future uncertainty and re-evaluating the feasibility to achieve desired conditions under climate change remains a critical component of decision making.

Activity: Values and Desired Conditions

To establish a participatory decision space inclusive of the diverse perspectives of land stewards as well as impacted rightsholders and stakeholders, workshop participants were asked to contribute their unique values and desired conditions for Minong during a facilitated, large-group discussion. Values and desired conditions were recorded by workshop facilitators prior to presenting findings of the biological science analyses described above. After results of the biological analyses were presented, workshop participants were asked to revisit previously stated desired conditions to evaluate whether they believed these conditions were threatened by climate change and if new desired conditions emerged.

Values for forest communities on Minong

Given their pre-existing knowledge of and experience on Minong, workshop participants discussed what they valued about forest communities on Minong broadly. Contributed values fell into multiple themes that included: forest diversity, the sensory experience of being in the forest, ecosystem services, intrinsic value, esthetic value, rarity, and the human connection to the forest through time (Table 5). Participants felt that all values were threatened by climate change, particularly air and water quality with more frequent high intensity fires. However, one participant noted that fire frequency may also enhance the value of forest diversity in terms of age and regeneration.

Table 5: Values for the forest communities on Isle Royale National Park (Minong), USA, contributed by land stewards and their partners during a workshop to evaluate climate adaptive decision making in wilderness.

Value Theme	Description	Illustrative Quotation
Forest diversity	Although Minong is a relatively small area, it includes significant ecological variability in terms of stand age, lake effects on local climate, soil depth, and past land use.	"It's highly variable because you have the influence of glaciation, where on the west end of the island there is a good amount of soil and on the east there's not. And then you have the influence from the lake…And then you also have the interplay of all these past land management activities and / or forest fires. It's just highly variable for the small space that it is."
Sensory experience	Being in the forest is a highly sensual experience full of changing sights, smells, and sounds which all contribute to a sense of connection with the island.	"I think of the forest as the breath of the island. I don't know how else to describe it. So for me the smells of the forest are really, so that touchy feely. The smells, the breathing, the respiration. And I think of that particularly for rain or lack of rain…And then I also think of safety or like a hug to me when I'm walking in the forest canopy…I have this sense of being enveloped in the environment in a way that to me feels very safe. Those are my sensory values."
Ecosystem services	The forest provides broad ecosystem services such as clean air and clean water, which could be threatened with climate change.	"I was thinking about clean water and clean air, which I know that's almost assumed, but you know what it's not really assumed anymore…if you start to get more fires, you're going to have some air issues, you're probably going to have some nutrient loading in the waters."

Table 5 (continued): Values for the forest communities on Isle Royale National Park (Minong), USA, contributed by land stewards and their partners during a workshop to evaluate climate adaptive decision making in wilderness.

Value Theme	Description	Illustrative Quotation
Intrinsic value	Even if participants don't spend much time there, the forests on Minong have value just in their existence.	"I haven't been to the island in many years, and I don't think I'll be up there in the near future either. Just can't take the boat ride anymore, but it's beautiful, and it's the parts that aren't visited, their sanctity; their prestige of that existence, you know."
Aesthetic value	The forests, particularly the older forests on the island have esthetic value to some participants.	"For me, it's the aesthetic."
Rarity value	Natural and cultural resources that are plentiful on Minong are becoming scarce on the mainland. The scarcer they become elsewhere, the more valuable they are on the island.	"I value the old forest, the sugar maple and yellow birch we have because while we have a lot of it on the island, there's decreasing amounts on the mainland." "I value [archaic sites] on the island specifically because much of it's actually really well preserved relative to the archaic mining and production sites on the mainland. Much of those areas have been looted out pretty heavily, and there's still intact archeological deposits that are over there on the island."
Multi-generational human-forest relationships	The interdependence through time between people and the forests on the island is valuable.	"Or the area that was a sugar bush, I couldn't wait to go to that space once I heard about it. Even though there's not a lot of physical evidence of it, just being in that space and knowing how it had been used before was just electrifying. What an incredible tie to that dependence [on the forest]."

Desired conditions for forest communities Minong

Workshop participants generated desired conditions for forest communities on Minong based on the values described in the previous exercise and on pre-existing goals and objectives (Box 2). The discussion resulted in five themes of desired conditions agreed upon by NPS and GPLSC staff: restore GPLSC's roots and connection to Minong; retain the unique biocultural identity of Minong; encourage natural processes like fire while also mitigating negative herbivory and human impacts, including those from climate change; ensure that cultural sites are preserved through time for future generations; and maintain multigenerational connections to Minong for visitors.

There was much discussion about how specific the desired conditions should be. Workshop participants decided that desired conditions should align with current management strategies, are aspirational, and could be achieved through actionable forest management objectives such as "maintain ten aspen groves for X number of hectares." Participants also noted that this list of desired conditions was not all-inclusive and could change over time.

Desired Conditions for Forest Communities on Minong

1) **Restore Grand Portage Band's roots and connections to Minong.**
    a. Protect and create high-quality habitat for fish, wildlife, and plants so they are there for the people for subsistence and gathering.
    b. Protection and enhancement for intrinsic value
2) **Retain the unique biocultural identity of Minong.**
    a. Conserve high levels of biodiversity for as long as possible.
    b. Using an objectives-based and place-based approach, manage for diverse ecosystems, including species, and cultural sites.
    c. Conserve forest resilience to disturbance to maintain forested systems on Minong.
3) **Encourage natural processes like fire while also mitigating negative herbivory and human impacts including climate change.**
4) **Ensure that cultural sites are preserved through time for future generations.**
    a. Ensure these areas are more resilient to climate change impacts through actions such as fuel reduction and prescribed fire or other treatments (e.g., trail and campsite rerouting).
5) **Maintain multigenerational connections to Minong for visitors.**

Box 2: A list of desired conditions for forest communities on Minong, Isle Royale National Park, Michigan, USA. Desired conditions were developed by National Park Service and Grand Portage Band of Lake Superior Chippewa natural resources staff and one Tribal Council member during a workshop in Grand Portage, Minnesota, in January 2025.

Restore Grand Portage Band of Lake Superior Chippewa's roots and connections to Minong

Workshop participants deeply valued humans' relationship with Minong through time, particularly the connections between the island and the GPLSC. Recognizing there have been many years of disconnect between the GPLSC and Minong, there was a strong desire to reconnect the Band with the island. To ensure cultural ties to the island persist or may be expanded (e.g., subsistence hunting and gathering) participants felt there was a need to protect and create high-quality habitat for fish, wildlife, and plants. Furthermore, even though many Band members have not been able to visit the island for many years, GPLSC still strongly cherishes the intrinsic value of the island. Therefore, there was a desire to protect and enhance Minong more generally.

Retain the unique biocultural identity of Minong

Participants described how they valued the rarity, uniqueness, and a variety of biocultural landscapes (i.e., unique ecotypes resulting from conditions created by historical climate, glaciation, and human land use) on Minong. Participants felt the diverse landscape, including the forest communities that inhabit it, is central to the island's identity. To retain the unique biocultural identity of Minong, participants felt that management should strive to conserve high levels of biodiversity for as long as possible. Further, the park should manage these diverse biocultural systems, including species and cultural sites, using an objectives-based and place-based approach. Participants felt that in order to maintain forested ecosystems on Minong in the face of climate change and increasing disturbance, they should aim to conserve forest resilience through management activities such as prescribed fire, cultural burning, or management of lightning-ignited fire.

Encourage natural processes like fire while mitigating negative herbivory and human impacts including climate change

NPS managers expressed that climate change makes managing Minong for its natural, untrammeled conditions challenging (i.e., allowing natural processes like fire and predator-prey population dynamics to proceed unhindered by humans). In comparison, participants from GPLSC emphasized the need to reintegrate humans into the environment on Minong through forest management practices rather than regarding humans as separate from nature. GPLSC representatives felt that engaging in more active forest management would help restore the historical human-nature balance and resilience of the forest communities of Minong.

Ensure that cultural sites are preserved through time for future generations

Many archeological and cultural sites exist within the forests on Minong, some of which have not been revealed or revisited for several decades. Participants discussed the vulnerability of these sites to high-severity fire. To ensure culturally significant sites are preserved for future generations, participants felt that fuel reduction, prescribed fire, or other treatments such as trail and campsite rerouting may be necessary to preserve sites for future generations. Participants discussed that ideally this work would be a collaborative effort between the NPS and the GPLSC.

Maintain multigenerational connections to Minong for visitors

Participants shared that Isle Royale National Park is "the most revisited national park." Thus, many of Minong's visitors have deep, multigenerational connections to the island. While recognizing that visitors can have some negative impacts on the island, NPS staff wanted to ensure that these connections be sustained into the future through actions that make the forest communities more resilient disturbance and human impacts, including climate change. The NPS recognized that to ensure sustained, multigenerational connections, more visitor use management may be needed (e.g., temporary closures and trail re-routing).

Potential climate change impacts on values and desired conditions

After presenting a summary of anticipated impacts of climate change on Minong's forest communities, workshop participants were asked if they were concerned about any of their previously stated values and if the desired conditions still felt feasible. Overall, participants were concerned about the potential impacts of climate change on values and desired conditions. However, they noted that climate change outcomes could "enhance" some values and desired conditions. For example, increased fire frequency could result in more opportunity for young forest regrowth and increased moose forage. Despite anticipated impacts, participants still felt the desired conditions they generated were relatively feasible and offered an important, co-produced vision for the island's forest communities.

Learning Objective 3: Understand the Utility of RAD as a Tool for Responding to Ecological Transformation

Since European settlement, ecological systems within the United States have been managed under the assumption of stationarity, or the tendency of environments to fluctuate within a range of historically known conditions (Jackson & Hobbs 2009; Magness et al. 2022; Milly et al. 2008; Young & Duchicela 2020). With this understanding, environmental properties may change in response to disturbance events, such as wildfire, but thereafter return to a known reference or stable state. Increasingly, however, land stewards are observing a shift in ecosystem state beyond a historical natural range of variability (Schuurman et al. 2022). Once ecological communities have crossed a threshold, it is often infeasible to restore historical ecosystem structure and function (Suding and Hobbs 2009). Management techniques that may have been previously employed to restore ecosystems following perturbation or strategies to promote resiliency through disturbance may no longer be effective at achieving desired conditions. Land stewards are therefore increasingly challenged to generate novel solutions to meet management mandates and objectives as the character of the landscapes they manage continues to shift.

Decision alternatives for wilderness in an era of climate change

The RAD framework was developed in response to the need to expand the decision space around ecological transformation under climate change. Rather than defaulting to familiar actions or strategies, the RAD framework provides a space for land stewards to evaluate the opportunities and costs of choosing to deliberately act to intervene (resist or direct) alongside the deliberate decision to not intervene (accept) in response to climate change-driven ecological transformation. This is particularly pertinent for federally designated wilderness, where accepting ecological change may be a familiar strategy due to real and perceived barriers to using active management (Cravens et al. 2024). Nevertheless, although active management is highly scrutinized in wilderness, such activities are not strictly prohibited. In some instances, resist strategies may be necessary to preserve or recover special status species, such as those listed under the Endangered Species Act. Direct strategies are often less familiar and may be viewed as high-risk strategies because few real-world examples exist outside manipulative experimental trials such as common garden and greenhouse experiments (Cravens et al. 2024). By carefully considering all potential alternatives and their implications for wilderness character qualities, land stewards may justify the use of minimum allowable tools to meet desired conditions in rapidly changing wilderness landscapes.

Activity: Generating RAD Alternatives

Before the RAD framework was introduced, workshop participants were divided into two smaller groups and asked to generate potential management responses to plausible transformations for forest communities on Minong (i.e. conversion of boreal forest to temperate forest and conversion of forest cover to non-forest cover). Participants were encouraged to freely generate decision alternatives, regardless of capacity limitations, constraints, or risks. Nine themes of alternatives emerged from exercises and ensuing conversations: inventory and monitoring, fire, planning, managing moose, co-stewardship, invasive species, visitor use, mechanical thinning, and planting.

Individual alternatives represented a broad range of resist, accept, and direct actions (Table 6). Alternatives that resist transformation of forest communities included mechanical thinning, treatment of invasive pests and plants, thinning around historical structures, cultural and prescribed fire, and seedbanking. Alternatives that directed transformation included planting native tree species that may be better adapted to future climatic conditions and planting new genotypes of native plant species from off-island seed zones. Several alternatives supported multiple RAD categories. For example, participants felt that co-stewardship and forest inventory and monitoring could be leveraged to inform resist or direct actions in the future. All alternatives involved maintaining or promoting forest communities, however, the composition of those communities may change depending on the alternative(s) selected.

While sorting decision alternatives into the three RAD categories, participants gained a shared understanding of how decision making is conducted differently on Tribal-administered lands than on federal government-administered lands. One participant expressed that stewardship decisions made on Tribal-administered lands were outcome-based rather than process-based. Alternatively, a participant from the NPS explained that decision making on federal lands must be inherently process-based to ensure decisions can be defensible in wilderness areas on Minong. NPS participants felt the RAD framework and other structured processes are tools that managers can leverage to demonstrate that decisions were made thoughtfully. Additionally, participants felt RAD alternatives could be streamlined with the NEPA planning process. In particular, accept strategies could be used as “no action” alternatives.

Participants from GPLSC expressed that acceptance of ecological change is a fundamental part of stewardship, because “nature is going to give you what nature is going to give you”. Rather than pre-determining resist, accept, and direct alternatives, one GPLSC participant felt these alternatives represented conversations with Mother Earth. Instead of placing alternatives in separate categories, alternatives were inherently interconnected and represented in every stewardship decision.

Table 6: Decision alternatives generated and categorized using the resist–accept–direct framework by participants in a workshop to assess climate adaptation strategies for boreal forest communities on Minong, Isle Royale National Park (Minong), USA.

Strategy Theme	Decision Alternative	Resist	Accept	Direct
Inventory and Monitoring	Complete stand-level forest inventory to update existing vegetation maps	X	X	X
	Monitor moose forage in burned areas	X	X	X
	Ground truth modeled vegetation layers	X	X	X
Fire	Planned ignition of prescribed or cultural fire	X		
	Research fire history on Minong		X	
	Allow lightning-ignited fire to burn	X	X	
	Identify areas and species that would benefit the most from prescribed fire	X		X
Planning	Develop forest management plan		X	
Managing Moose	Restore subsistence harvest of moose	X		X
	Moose capture and removal			X
	Moose contraception	X		X

Table 6 (continued): Decision alternatives generated and categorized using the resist–accept–direct framework by participants in a workshop to assess climate adaptation strategies for boreal forest communities on Minong, Isle Royale National Park

Strategy Theme	Decision Alternative	Resist	Accept	Direct
Co-Stewardship	Improve or develop co-stewardship agreements and planning	X	X	X
Invasive Species	Control or prevent spread of invasive species, such as woody shrub species	X		
	Chemical treatments for defoliators	X		
Visitor Use	Manage visitor use access	X	X	X
Mechanical Thinning	Thinning forests where spread of forest pests is observed or expected	X		
	Thinning around historical buildings, structures, cultural sites, and archaeological sites	X		
Planting	Supplemental planting of moose browse species	X		
	Planting of white pine or other boreal species better adapted to increasing fire and increasing temperatures			X
	Plant new genotypes of native species from distant seed zones			X
	Seedbanking of island seeds and growing out for planting efforts	X		
	Underplanting balsam fir	X		X
	Aerial seeding	X		X

Learning Objective 4: Develop a Feasible and Repeatable Workflow to Evaluate RAD Decision Alternatives

Selecting and applying decision alternatives generated using the RAD framework can be challenging. No matter how much observation, ecological modeling, and experimentation has been applied to characterize the ongoing or potential transformation, some uncertainty likely persists. In addition, institutional constraints may limit the ability of managers to feasibly pursue some alternatives. To effectively respond to ecological transformation and fulfill institutional mandates and objectives, land stewards must therefore work with uncertainty (for example, by using scenario planning and adaptive management approaches) and operate creatively within constraints (for example, by collaborating with adjacent management units with different constraints).

Balancing social-ecological trade-offs

In addition to grappling with uncertainty, wilderness stewards must also balance social-ecological trade-offs inherent in decision making under climate change. These trade-offs are a negotiation of the unique values each member of the planning or project team contributes, balanced with policy requirements under guiding strategic management plans and laws such as the National Environmental Policy Act (NEPA) and the Wilderness Act. In federally designated wilderness, selecting and implementing a decision alternative should minimize undesirable outcomes as well as impacts that may degrade wilderness character. For example, preserving special status, iconic species may be considered a high priority for managers to fulfill requirements pursuant to the Endangered Species Act (16 U.S.C. 1531-1544) as well as to maintain or preserve the natural quality of wilderness (see Table 1 for definitions of wilderness character qualities). Nevertheless, the type of management action pursued to support species persistence may conflict with policy under the Wilderness Act. Management actions that seek to halt or reverse ecological change for single-species preservation align most closely with a resist strategy. However, resist actions often require trammeling of wilderness to meet necessary targets for viable populations. Furthermore, under climate change, it is becoming less common that single actions will be sufficient to support species persistence, thereby necessitating more intensive and enduring management efforts, and thus greater and often more sustained trammeling (Evans et al. 2016). In the long-term, a resist strategy may reduce undesirable outcomes associated with species loss, but this strategy may also degrade wilderness character through multiple acts of trammeling. Under an accept strategy, where no active management takes place, wilderness character may not be degraded by trammeling; however, the natural quality of wilderness may be compromised if an iconic species is lost. Finally, under a direct strategy, individuals or populations may be translocated to other, more climatically suitable areas of the landscape where they may persist autonomously. Translocating the species would necessarily involve trammeling associated with capturing individuals in the source site, and such trammeling would be greater if the destination site were also within wilderness. However, unlike the resist strategy, this strategy, if successful, may not entail repeated acts of trammeling because the translocated species would be expected to be self-sustaining in the destination site. Ultimately, for management decisions to be defensible, it is critical to explicitly account for all potential impacts and associated social-ecological tradeoffs, as well as key uncertainties, associated with implementing a decision alternative.

The Futures Wheel: An exercise to illuminate trade-offs

To help clarify sources of uncertainty and social-ecological trade-offs inherent in climate change-informed decision making, we used the Futures Wheel tool to evaluate the potential implications and tradeoffs of resist, accept, and direct strategies on Minong. The Futures Wheel is a structured brainstorming tool used to describe multi-level consequences of addressing social-ecological change (Bengston 2015; Bengston et al. 2022). The Futures Wheel has been applied in a diversity of sectors to analyze consequences of many types of change, but it has rarely been used in climate adaptation planning. Considering climate adaptation actions in wilderness demands a transparent process to understand the potential consequences of decisions to act, or not to act. There are many ways to design and apply the Futures Wheel, however, in its basic structure, it requires users to define multiple arcs of consequences that stem from a central problem or event. Individual arcs describe a hierarchy of connected consequences. First-order consequences occur as a direct result of the central decision point or event. Second-order consequences are triggered by first-order consequences. Third-order and all subsequent consequences are directly informed by the preceding order. Arcs are extended as far as necessary, such that all potential consequences have been identified for each arc. The purpose of building arcs is to clarify all potential impacts, likely or unlikely, that stem from a central problem or event. By following this process, users can reduce unforeseen impacts and identify consequences that may be particularly beneficial or catastrophic (Bengston et al. 2022). Furthermore, by explicitly describing and recording all potential implications of implementing a decision, this process fosters transparency in decision making. After all arcs have been completed, users can score each consequence in terms of likelihood and desirability (Table 7). Final scores can then be summarized across the wheel to generate a quantitative understanding of the drawbacks and opportunities of a central problem or event.

Activity: Applying the Futures Wheel to RAD Decision Alternatives

To further evaluate decision alternatives generated during the workshop, individual Futures Wheels were used to illuminate potential consequences (positive, negative, or neutral) of selecting either a resist, accept, or direct action to address ecological transformation for boreal forest communities on Minong. First, all workshop participants worked together to generate a Futures Wheel for the accept alternative. After completing the accept wheel, workshop participants were divided into two smaller groups including participants from a range of positions, tenure, and affiliations. Each group constructed one wheel focused on either a resist or direct alternative (Box 3). Decision alternatives were placed at the center of each wheel such that subsequent arcs described direct and indirect implications associated with implementing each alternative. Workshop participants were encouraged to consider a range of potential consequences, including social, legal, and ecological consequences. Participants then scored each unique consequence by its likelihood and desirability (Table 7). In some cases, participants were not able to provide consensus scores for each consequence. Likelihood described the perceived possibility that each consequence would come to pass and was scored on a scale from 1-9. Desirability described perceived appeal of each potential consequence and was scored along a weighted scale such that perceived catastrophic consequences received a score of -50 and triumphant consequences received a score of 50. Workshop participants used the scores to gather a general sense of whether each alternative felt desirable and whether the cascading consequences were certain. Importantly, the intention of the futures wheel exercise was to explore the implications of each RAD alternative, not direct participants on how to proceed with management.

Table 7: Scoring method for a Future's Wheel activity examining the implications of choosing to resist, accept, or direct ecological transformation for boreal forest communities on Minong, USA.

Likelihood		**Desirability**	
9	Extremely likely	50	Triumph
8	Very likely	5	Extremely desirable
7	Likely	4	Very desirable
6	Somewhat likely	3	Desirable
5	Uncertain	2	Somewhat desirable
4	Somewhat unlikely	1	Minimally desirable
3	Unlikely	0	Neutral
2	Very unlikely	-1	Minimally undesirable
1	Extremely unlikely	-2	Somewhat undesirable
		-3	Undesirable
		-4	Very undesirable
		-5	Extremely undesirable
		-50	Catastrophe

RAD Alternatives: Tobin Harbor

To better envision social-ecological trade-offs among competing RAD alternatives, workshop participants chose to focus on a discrete geographic area on Minong. Tobin Harbor is a drainage on the northeast end of Minong where boreal forest is abundant. The drainage encompasses Mt. Ojibwe and extends to the edge of the 2021 Horne Fire burn scar. Tobin Harbor is close to one of the most developed areas on Minong—Rock Harbor.

RESIST

Use cultural/prescribed burning to maintain historical boreal forest composition and structure and restore cultural relationships with the land in areas federally designated as wilderness. Use drip torches to ignite fire. Use is limited to promote species persistence and species habitat (e.g., blueberry and wildlife habitat) and protect cultural sites and historical structures. Active participation by the Grand Portage Band of Lake Superior Chippewa.

ACCEPT

Allow lightning-ignited fires to burn. Suppress wildfire around structures or development. This alternative aligns with the current wildfire management strategy on Minong.

DIRECT

Use cultural burning followed by planting and monitoring to promote growth, proliferation, and age class diversity of forest species that may be better adapted to emerging climatic conditions and disturbance regimes. Use drip torches to ignite fire. Active participation by the Grand Portage Band of Lake Superior Chippewa. Hand planting or direct seeding of tree species (sugar maple, red maple, white pine). Add exclosures to protect plantings.

Box 3: Alternative actions proposed to resist, accept, or direct anticipated ecological transformation for forest communities on Minong, Isle Royale National Park, USA. Workshop participants discussed the cascading implications of each alternative both in terms of their desirability in achieving desired conditions and likelihood of occurring if the alternative was implemented.

Resist: Prescribed fire

The resist alternative focused on reducing the likelihood of high-severity, stand-replacing wildfire and promoting the persistence of important cultural species and moose browse in Tobin Harbor. Overall, consequences of this strategy were viewed as somewhat to highly likely and somewhat desirable to desirable (Figure 9). First order consequences of the resist alternative included presence of fire on the ground, temporary trail or zone closures, and relationship building with GPLSC Tribal members and staff.

Participants felt fairly certain of the ecological outcomes of this alternative, given that prescribed fire is a highly controlled and well-practiced activity. Participants agreed that unintentional escaped fire could occur, which could result in undesirable high-intensity wildfire under certain conditions. Additionally, prescribed fire would likely contribute to short- to long-term impacts on wildlife distribution, which participants felt was neither desirable nor undesirable. Despite potential negative consequences, opportunity to create mosaic habitat through use of fire aligned with participants' desired conditions for forest communities on Minong and was therefore viewed as desirable.

Workshop participants identified several positive and negative social consequences of the resist alternative, including opportunities for co-stewardship, shared learning, public backlash, and education. For example, temporarily closing trails for prescribed fire activities may impact visitor experience and lead to general visitor unhappiness. Alternatively, relationship-building between NPS staff and GPLSC was viewed very favorably. Participants felt that relationship-building could have beneficial cascading impacts such as integrated crews, opportunities for shared stewardship, and cross-training and shared learning opportunities.

Overall, participants felt that implementing this alternative would represent a breakthrough success for forest communities on Minong, relationship building with the GPLSC, and had the potential to set precedent for the use of fire as an important stewardship tool for national parks and wilderness in an era of climate change. One participant expressed that a decade ago, alternatives that included prescribed or cultural fire would not have been permissible in wilderness. However, with the growing recognition of climate change as a threat to wilderness character and societal changes in how prescribed fire is viewed as a management tool, this alternative may now be possible. Furthermore, acknowledgment that humans are a part of the landscape and have been active stewards in shaping the landscape for millennia has created opportunities to consider active intervention as a viable option. Participants felt that these societal changes may allow them to interpret the language of the Wilderness Act differently than how it may have been interpreted in the past.

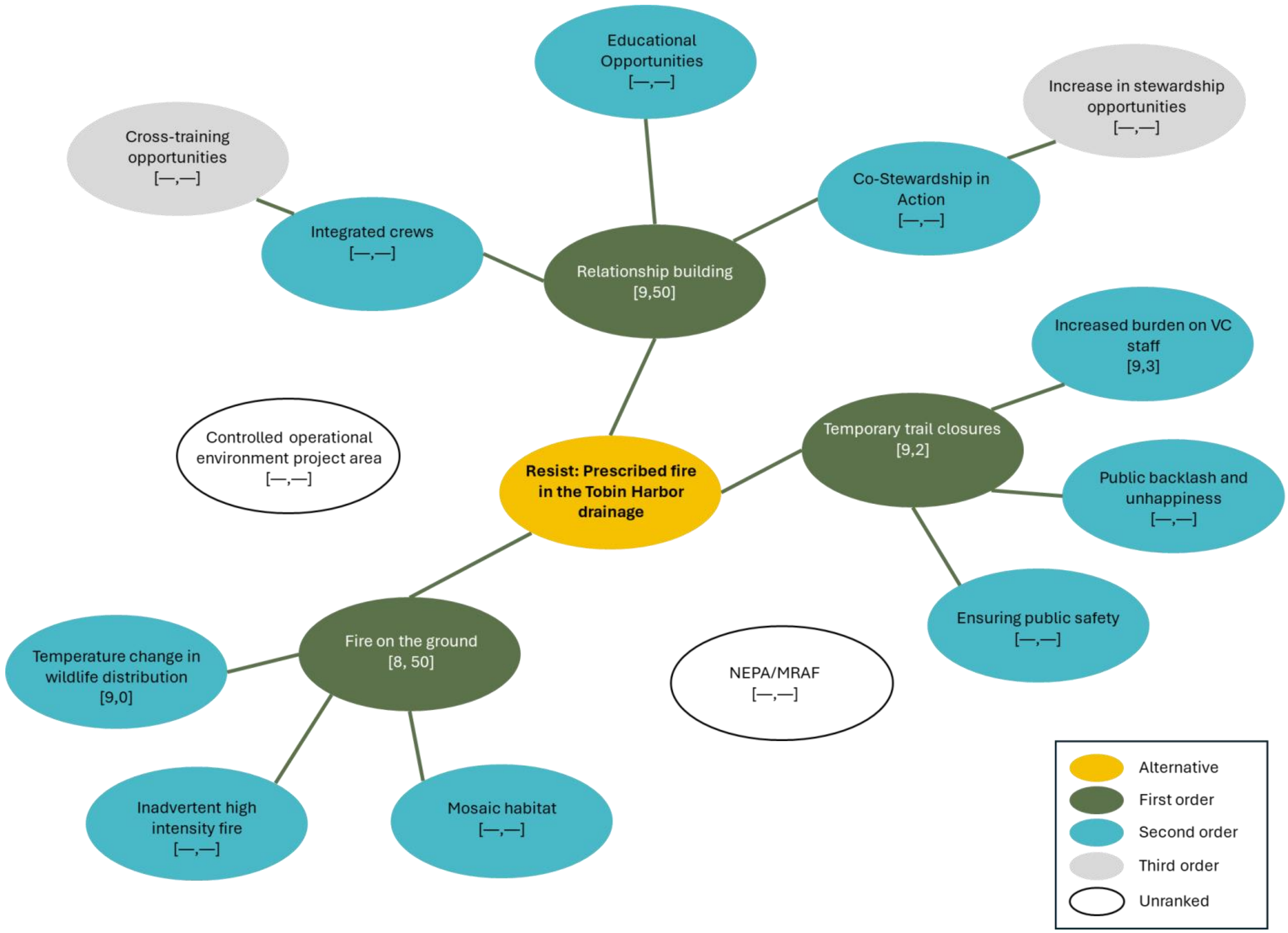


Figure 9: A Futures Wheel used to illuminate the potential cascading implications of choosing to resist anticipated ecological transformation of boreal forest communities on Minong, Isle Royale National Park, USA, by using prescribed fire. Implications (green, blue, and gray circles) were scored by the likelihood that they may occur because of the decision (first number in brackets) and by their perceived desirability (second number in brackets). Likelihood was scored on a scale from 1 (extremely unlikely) to 9 (extremely likely) and desirability was scored along a weighted scale from -50 (catastrophic consequences) to 50 (triumphant consequences); see Table 7 for additional details regarding scoring. Some implications were not scored (dashes) because of time constraints.

Accept: Allow lightning-ignited fires to burn

The accept alternative focused on allowing forest communities in Tobin Harbor to change in response to natural, lightning-ignited fires. Many of the social consequences of this alternative were viewed as extremely undesirable, and some were catastrophic (Figure 10). Ecological, recreational, institutional, and legal implications were identified in potential cascading effects of this alternative.

Many of the first order consequences were perceived as negative. For example, first order consequences included direct tree and wildlife mortality, smoke, temporary closures and evacuations, damage to archaeological sites, allocation of resources for fire response, and spread of high intensity fire outside Tobin Harbor. Additionally, participants acknowledged that allowing lightning-ignited fires to burn could also result in loss of human life, which would have substantial implications for future fire management and for trail access. Although several first order implications were perceived negatively, they often led to favorable outcomes over time. For example, tree mortality could lead to increased forest diversity (i.e., age and vegetation type) and snags and logs could provide more habitat for species like bats and owls. Participants perceived social consequences negatively, including: evacuations, potential loss of human life, and negative public perception. However, participants felt that many of the ecological consequences would be positive. For example, increasing forest diversity, increasing browse, and reducing surface fuels would have long-term beneficial impacts for forest communities.

Overall, the social and ecological complexity inherent in allowing lightning-ignited fire to burn made it difficult for participants to determine whether this alternative would be desirable. Additionally, unpredictable weather conditions on Minong made it difficult for all participants to determine the likelihood of potential consequences, such as fire spread and intensity. On Minong, humidity from Lake Superior can quickly extinguish fire. Alternatively, increasingly dry summer conditions combined with strong winds can quickly carry fire and spread it to areas that would require more significant suppression efforts to save structures and ensure the safety of visitors. NPS participants expressed that recent memory of the Horne Fire and its impacts influenced how they felt about uncontrolled fire. In particular, allowing fire to burn into areas with structures or into more remote wilderness areas with high recreation use by visitors was viewed negatively based on previous experiences during the Horne Fire. Participants from GPLSC further expressed the fire spirits made decisions about how fire would spread and how communities would be impacted, which made them feel as though their perceived desirability of certain consequences was irrelevant. For example, participants felt the fire spirits would determine whether to reveal and share culturally significant archaeological sites. Although exposure of sites might lead to vandalism by park visitors, participants felt that revealing these sites was an intentional consequence.

Figure 10: A Futures Wheel used to illuminate the potential cascading implications of choosing to accept ecological transformation of boreal forest communities on Minong, Isle Royale National Park, USA, by allowing lightning ignited fires to burn. Implications (green, blue, and gray circles) were scored by the likelihood that they may occur because of the decision (first number in brackets) and by their perceived desirability (second number in brackets). Likelihood was scored on a scale from 1 (extremely unlikely) to 9 (extremely likely) and desirability was scored along a weighted scale from -50 (catastrophic consequences) to 50 (triumphant consequences); see Table 7 for additional details regarding scoring. Some implications were not scored (dashes) because of time constraints.

Direct: Prescribed fire and planting of climate-adapted species

The direct alternative focused on increasing forest resilience to changing climate and disturbance regimes by implementing prescribed fire and planting those boreal species that may thrive in more temperate conditions (Figure 11). Ecological, cultural, institutional, and legal implications were identified in potential cascading effects of directing the transformation. Many of the implications identified in the direct Futures Wheel exercise were broad in nature (e.g., "expand capacity" and "enhance wildlife habitat"). Overall, participants felt this strategy would lead to the desired conditions of increasing forest resilience and of restoring GPLSC roots and connections to Minong through co-stewardship.

First order consequences of the direct alternative (i.e., improve climate resilience, perceived conflict with Wilderness Act, and implement co-stewardship) were generally viewed as neutral or overwhelmingly positive. However, throughout each arc of the wheel, there was a mix of positive and negative ecological and social consequences. Positive ecological outcomes (including two perceived as triumphs) included enhanced wildlife habitat, enhanced species of cultural significance, and improved resilience to climate change and fire. Yet, there were also several potential negative outcomes including loss of older-growth forest, post-fire colonization by invasive species, and low regeneration due to herbivory. Additionally, participants were relatively uncertain about the impact directing the transformation would have on deciduous defoliators.

Participants felt that the social and cultural consequences related to the GPSLC were largely positive. For example, participants felt this alternative would support Indigenous literacy with Tribal rights and history. Alternatively, participants felt that societal perception of this alternative may be neutral or negative; for example, public perception of conflict with the Wilderness Act and backlash from the public regarding co-stewarding the park with GPLSC. Institutional implications were projected to be both positive and negative. Positive institutional implications included expanded capacity by both the NPS and GPLSC, relationship building, sharing of indigenous knowledge with the NPS, and coalition building with others. However, participants recognized these positive outcomes could likely result in increased workloads, particularly around policy if there were perceived conflicts with the Wilderness Act.

Most legal implications came from first-order consequences of perceived conflict with the Wilderness Act and the implementation of co-stewardship. Although participants perceived legal implications resulting from perceived conflict with the Wilderness Act were negative, they felt that legal implications of co-stewardships would eventually lead to positive outcomes. For example, participants felt that co-stewardship actions had potential to be litigated, which would not be favorable. However, if litigated, participants felt that it would likely result in a Supreme Court decision that upholds the co-stewardship action and sets a positive precedent for co-stewardship of other federal lands.

Figure 11: A Futures Wheel used to illuminate the potential cascading implications of choosing to direct ecological transformation of boreal forest communities on Minong, Isle Royale National Park, USA, by using prescribed fire and planting trees species better adapted to emerging climatic conditions. Implications (green, blue, and gray circles) were scored by the likelihood that they may occur because of the decision (first number in brackets) and by their perceived desirability (second number in brackets). Likelihood was scored on a scale from 1 (extremely unlikely) to 9 (extremely likely) and desirability was scored along a weighted scale from -50 (catastrophic consequences) to 50 (triumphant consequences); see Table 7 for additional details regarding scoring.

Key take-aways and findings from the Futures Wheel exercise

- Using prescribed fire would foster valuable co-stewardship among NPS, GPLSC staff and Tribal members
- Participants were less certain of the consequences of an accept strategy because of complex social-ecological interactions
- Participants noted many negative consequences to an accept strategy, although this alternative reduces the most trammeling in the near term
- Previous experiences with the Horne Fire of 2021 and spiritual beliefs shaped how participants viewed desirability of consequences
- Participants felt that, although the ranking was time-consuming, it was useful for facilitating conversation and evaluating whether an alternative helped meet desired conditions

Conclusions and Considerations for Future Work

Addressing climate change in congressionally designated wilderness is a wicked problem faced by land stewards throughout the United States. The purpose of this case study was to begin to untangle this wicked problem by examining the ecological and social impacts of climate change and by demonstrating an iterative process that land stewards and their partners may use to mindfully address climate change-driven ecological transformation in wilderness. The case study described in this report specifically addresses the wicked problem of managing for projected ecological transformation of forest communities on Minong, Isle Royale National Park, United States. Scientists at the Aldo Leopold Wilderness Research Institute (ALWRI) researched the potential ecological impacts of projected climate change on forest communities as well as how those impacts are perceived by land stewards. Following this research, ALWRI scientists facilitated a 2-day workshop with National Park Service (NPS) staff and natural resources staff from the Grand Portage Band of Lake Superior Chippewa (GPLSC) to introduce an adaptive management process incorporating the RAD framework to generate and evaluate a decision space for addressing climate change-driven transformation of forest communities on Minong.

Workshop participants valued many aspects about forest communities on Minong including the many sensory experiences the diverse forests on Minong elicit, the human connection to the forest through time, several ecosystem services the island provides such as clean air and clean water, and the aesthetic, rarity, and intrinsic values of the island. These values contributed to the desire to restore GPLSC's connection to Minong, retain the unique biocultural identity of the island, encourage natural processes while also mitigating for negative impacts in an era of climate change, ensure the preservation of cultural sites, and maintain multigenerational connections for visitors. Although climate change is anticipated to impact all values, participants acknowledge that some of these impacts may be positive. Additionally, participants maintained that their identified desired conditions were an important first step in creating a shared vision for Minong in the face of climate change.

Workshop participants generated a wide variety of decision alternatives to address ecological transformation of forest communities. Regardless of specific objectives, all alternatives included engaging in activities to understand or conserve forest communities on Minong. Several strategies involved the use of prescribed fire or planting to promote forest health or alter forest composition to avoid overall loss of forest cover. Participants were particularly interested in relationship-building to facilitate co-stewardship of forests, including working together to implement cultural and prescribed fire on the landscape. All participants felt the use of prescribed fire would be a breakthrough success for the island, both in terms of meeting desired conditions as well as setting a precedent for use of human-ignited fire in national parks and wilderness. However uncommon, there is already some precedent for using human-ignited fire in wilderness that workshop participants did not reflect on. Worsham et al. (2025) highlight longstanding wilderness prescribed fire programs in Yosemite National Park, the Bob Marshall Wilderness Complex, and in North Cascade National Park. Therefore, there is already precedent for the use of human-ignited fire in wilderness management, and Isle Royale National Park could add to that precedent if they pursue cultural and/or prescribed fire in the future.

Relationship-Building and Co-Stewardship

Workshop participants expressed a shared desire to continue to build relationships and engage in co-stewardship opportunities between the GPLSC and the NPS. One participant expressed that the workshop was the first time staff from both the GPLSC and the NPS had come together to define shared values and brainstorm co-stewardship strategies to address climate change-driven transformation of forest communities on Minong. Participants discovered they had many shared values and many of the same capacity limitations for addressing climate change threats. For example, all participants agreed they had limited time and staff to implement research and management activities, such as forest inventory. However, participants felt that if they combined efforts, they could potentially pursue more intensive activities such as prescribed fire. Participants also discussed a tribal hunt to assist with moose management on Minong. However, NPS staff's lack of authority to grant permission for a Tribal harvest, anticipated negative perception by visitors on Minong, and the Tribe's concerns surrounding litigation have prevented individuals from either the NPS or GPLSC from pursuing a hunt further. Nevertheless, participants felt the discussion that occurred during the workshop was an important step in working toward actionable outcomes. Overall, participants felt the workshop was helpful in framing a collective long-term vision for the future of forest communities on Minong.

Filling Knowledge Gaps

Land stewards are often tasked with making decisions with incomplete knowledge and high uncertainty in rapidly changing landscapes. The tools outlined in this report are meant to support high-risk decision making under climate change. However, the ability to anticipate ecological change as well as the effectiveness of management activities to address change and meet desired conditions hinges on the ability of managers to continue to learn and adapt. Research and monitoring are necessary activities to accelerate learning. Workshop participants identified a need to inventory forest communities and monitor trends in forest conditions on Minong. Participants mentioned existing vegetation maps that require updating. Additionally, managers discussed using available Forest Inventory and Analysis data, remote satellite imagery, and light detection and ranging (LiDAR) to identify and ground truth vegetation communities. Inventory would include assessment of overstory and understory shrub layers. Participants from GPLSC expressed particular interest in inventorying moose browse. By leveraging the modeling results generated for this case study along with field-collected data, managers can begin to fill knowledge gaps and build more robust and defensible decisions.

Identifying Ecological Thresholds or Trigger Points

When and where to apply RAD alternatives remains a complex topic that requires further consideration. Ecological transformation has been described as a continuum of irreversible change that may increase in magnitude over time (Hillebrand et al. 2020). In that respect, it may be more appropriate for land stewards to identify specific features or ecological processes that, if degraded or lost, might trigger management actions. Limits of acceptable change (LAC) is one example of a tool wilderness managers may use to decide if or when to implement management actions to either resist or direct observed ecological change (Stankey and McCool 1984). LAC was initially developed to inform the management of recreation in wilderness. More recently, LAC has been revisited to understand how it can be applied in a multi-use framework (McCool and Cole 1997). Additionally, others have developed guidance to identify ecological thresholds and trigger points to inform shifts in RAD pathways (Lynch et al. 2025). Wilderness managers may use these tools and guidance or develop their own to decide how much ecological change may be acceptable and to justify when active management may be necessary to minimize undesirable outcomes.

Timelines for Application

For any climate adaptation process to be successful in the long-term, it is important to establish a timeline to revisit and re-evaluate key decisions and desired conditions on a recurring basis (Stein et al. 2014). There are several obstacles that can make it difficult to adhere to re-evaluation timelines, including insufficient resources or capacity, turnover in leadership and staffing, and competing priorities. Some of these obstacles can be overcome by developing and maintaining partnerships, planning ahead to secure appropriate resources and tools, keeping detailed and accessible records, and designating appropriate timelines that may coincide with existing planning revisions or amendments (Månsson et al. 2023). Throughout this case study, land stewards highlighted the need for continued and growing partnerships, identified knowledge gaps and uncertainties for further investigation, and evaluated desired conditions and potential outcomes of divergent decision alternatives to meet desired conditions. The skills acquired during the workshop can be used to support, rather than replace, existing planning and projects.

Incorporating RAD into Existing Planning

The RAD framework design is intentionally simple so that it can be applied to existing planning strategies and processes (Schuurman et al. 2022; 2025). While similar discussions and conversations may already be a part of existing protocols, the process outlined in this report allows land stewards to build a transparent, repeatable process that can be applied in a wide variety of contexts to support defensible decision making. For example, the RAD framework may be used to structure decision alternatives as required under the National Environmental Policy Act (NEPA). The accept option of RAD aligns well with the no-action alternative for NEPA, whereas the resist and direct options may be considered alternative actions. For a Minimum Requirements Analysis (MRA), RAD may similarly be used to generate divergent decision alternatives for further evaluation. Importantly, including the Futures Wheel exercise as a tool alongside RAD in adaptation planning can illuminate consequences of each alternative when determining whether action may be necessary to achieve specific objectives or improve certain wilderness character qualities. This step can be overlooked in adaptation planning processes, but for the wilderness context, it is essential. In conclusion, the skills and tools explored for this case study and introduced during the workshop are intended to support increasingly complex decision making in wilderness by integrating adaptation thinking into existing planning processes.

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APPENDIX

Appendix A

Detailed results of the biological analysis of climate change impacts to forest communities on Minong, Isle Royale National Park, United States. Results are in alphabetically order by tree and shrub species.

Appendix B

Key themes about climate change and climate-informed adaption responses derived from a series of seven semi-structured interviews with NPS and Grand Portage Band of Lake Superior Chippewa staff focused on impacts to boreal forest communities on Minong and on Tribal trust lands.

Appendix A

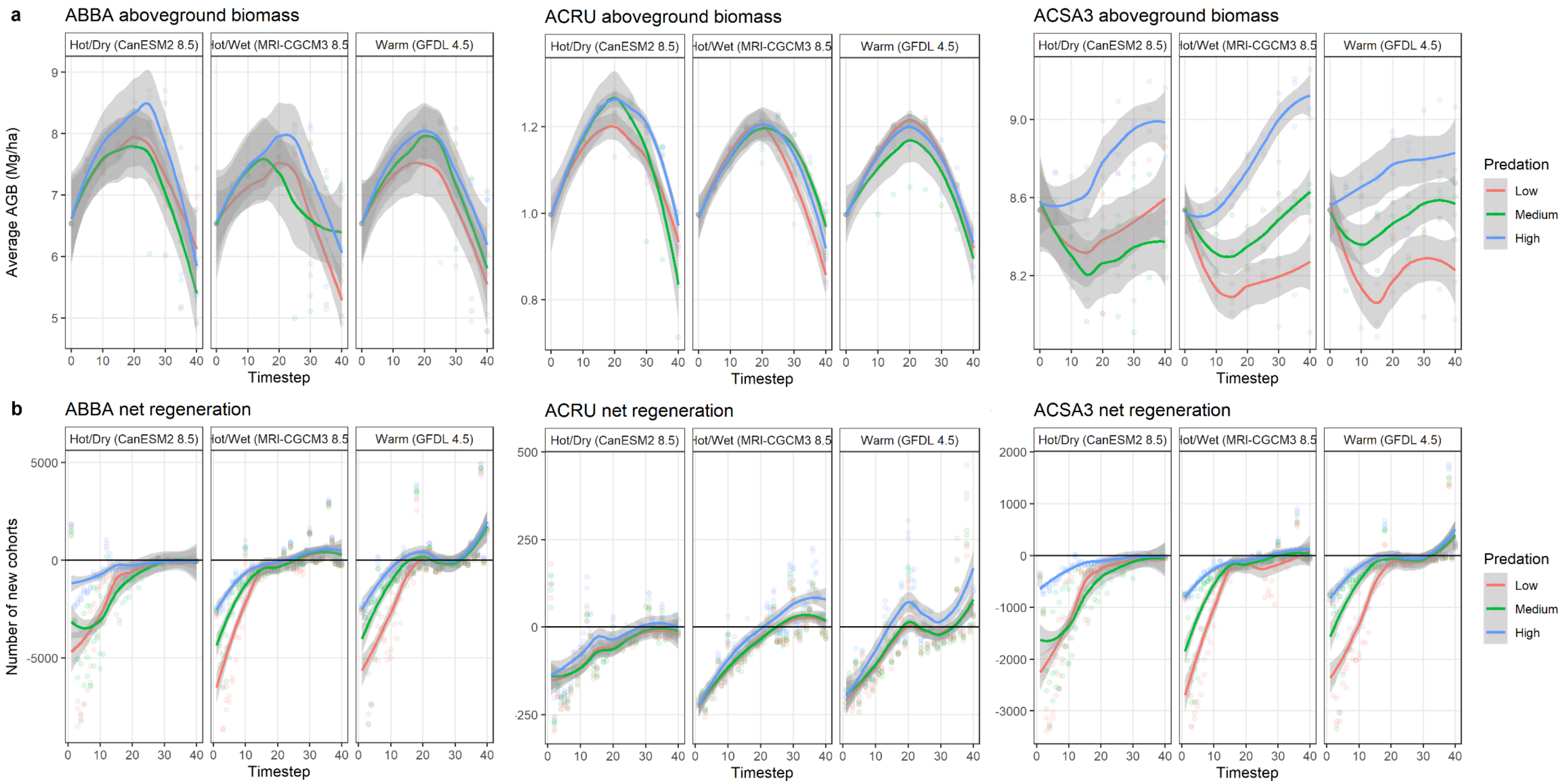

Figure 1: Projected trends in a) aboveground biomass and, b) net regeneration for balsam fir (*Abies balsamea*), red maple (*Acer rubrum*), and sugar maple (*Acer saccharum*) under three climate change futures and for three levels of predation intensity on moose populations from 2020-2060 on the island of Minong, Isle Royale National Park, USA.

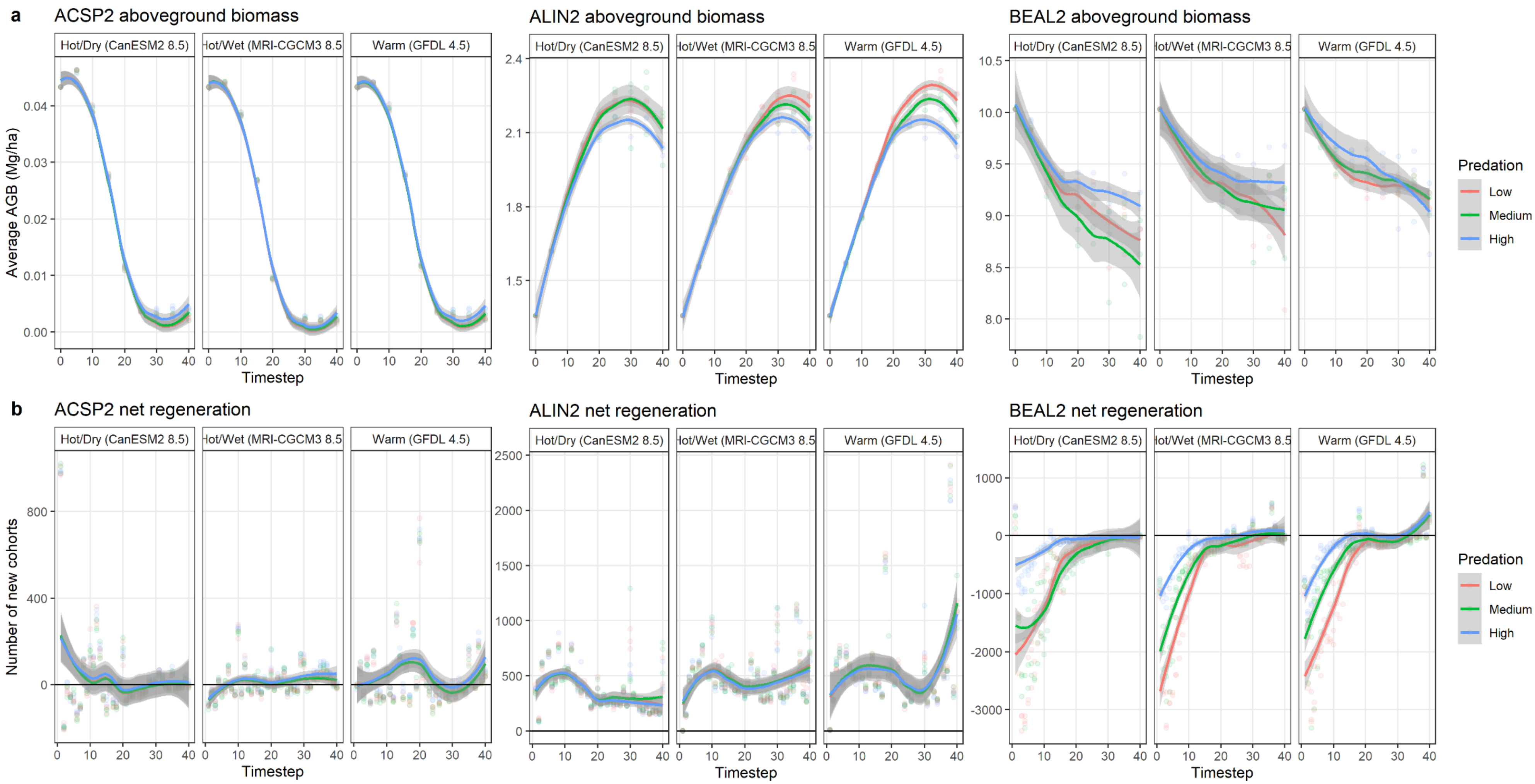

Figure 2: Projected trends in a) aboveground biomass and, b) net regeneration for mountain maple (*Acer spicatum*), gray alder (*Alnus incana*), and yellow birch (*Betula alleghaniensis*) under three climate change futures and for three levels of predation intensity on moose populations from 2020-2060 on the island of Minong, Isle Royale National Park, USA.

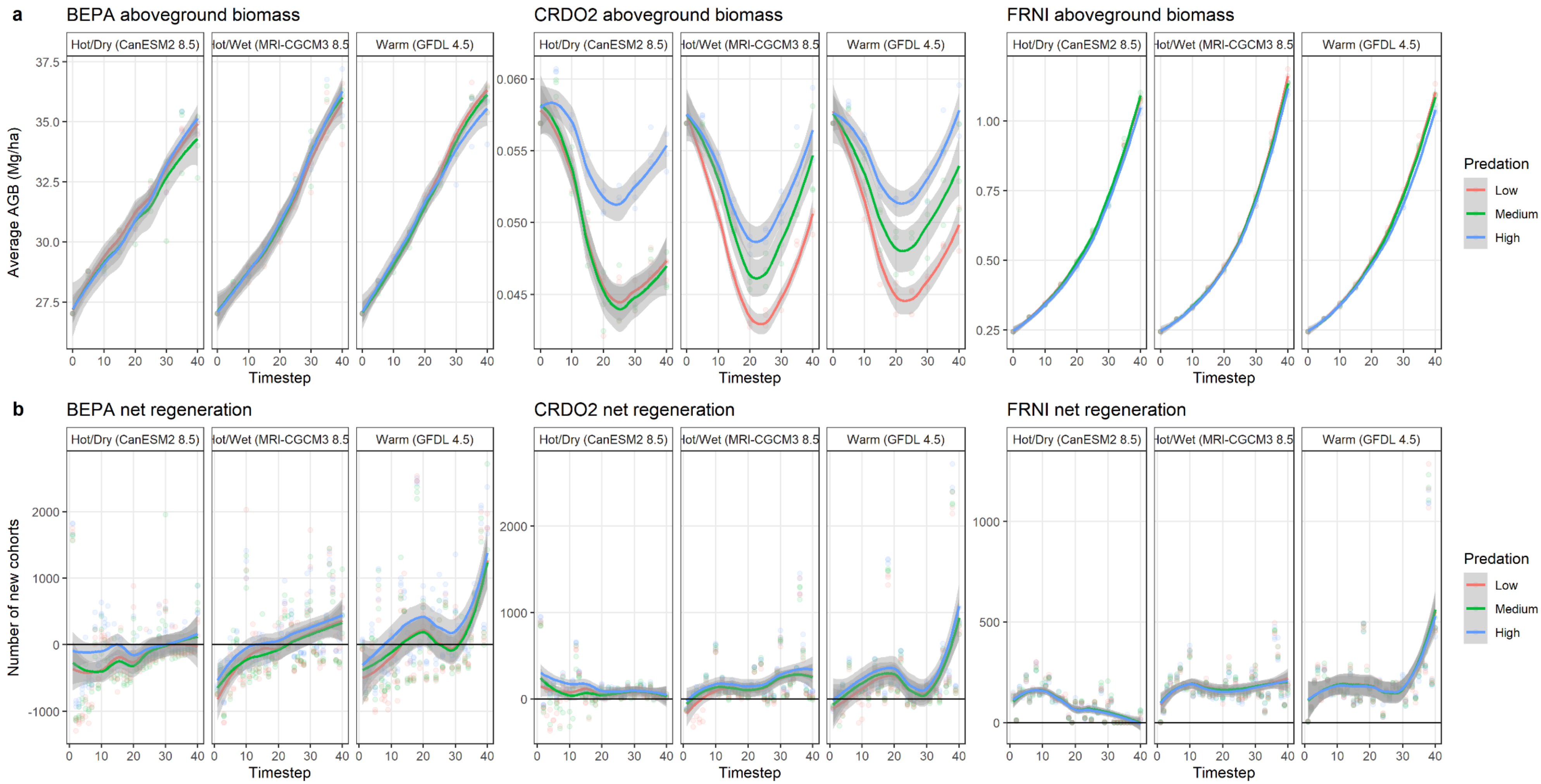

Figure 3: Projected trends in a) aboveground biomass and, b) net regeneration for paper birch (*Betula papyrifer*), black hawthorn (*Crataegus douglasii*), and black ash (*Fraxinus nigra*) under three climate change futures and for three levels of predation intensity on moose populations from 2020-2060 on the island of Minong, Isle Royale National Park, USA.

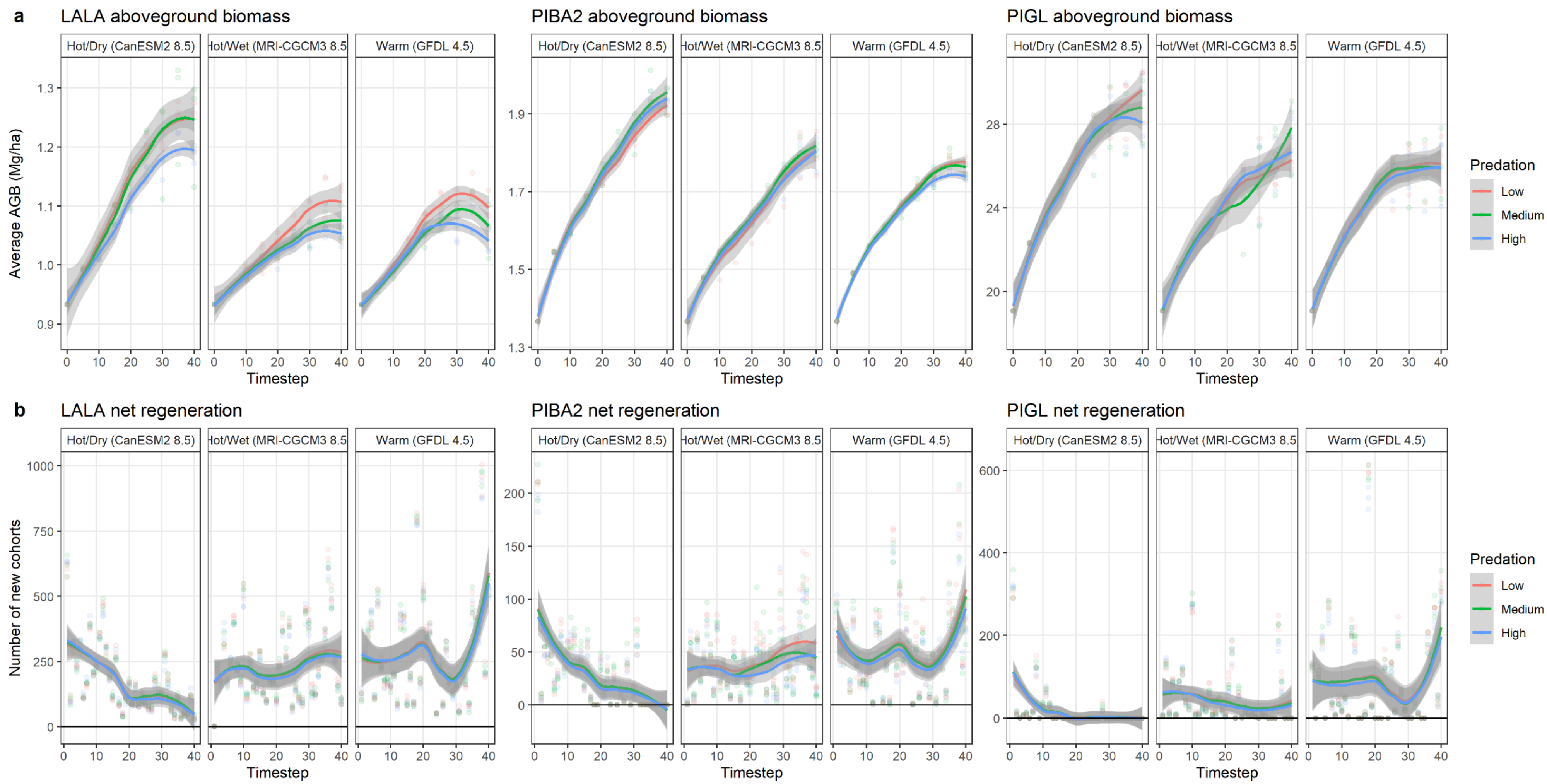

Figure 4: Projected trends in a) aboveground biomass and, b) net regeneration for larch (*Larix laricina*), jack pine (*Pinus banksiana*), and white spruce (*Picea glauca*) under three climate change futures and for three levels of predation intensity on moose populations from 2020-2060 on the island of Minong, Isle Royale National Park, USA.

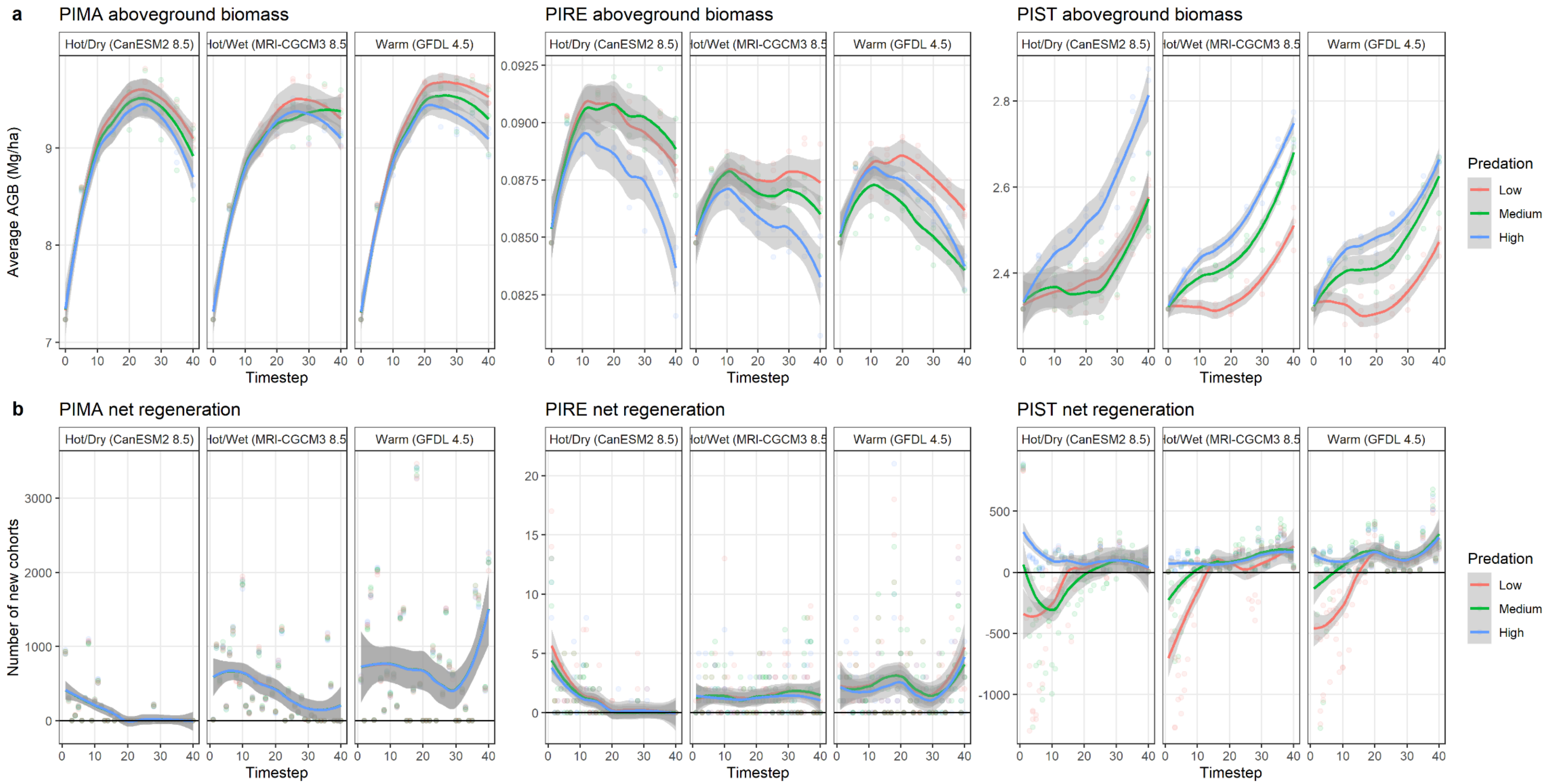

Figure 5: Projected trends in a) aboveground biomass and, b) net regeneration for black spruce (*Picea mariana*), red pine (*Pinus resinosa*), and eastern white pine (*Pinus strobus*) under three climate change futures and for three levels of predation intensity on moose populations from 2020-2060 on the island of Minong, Isle Royale National Park, USA.

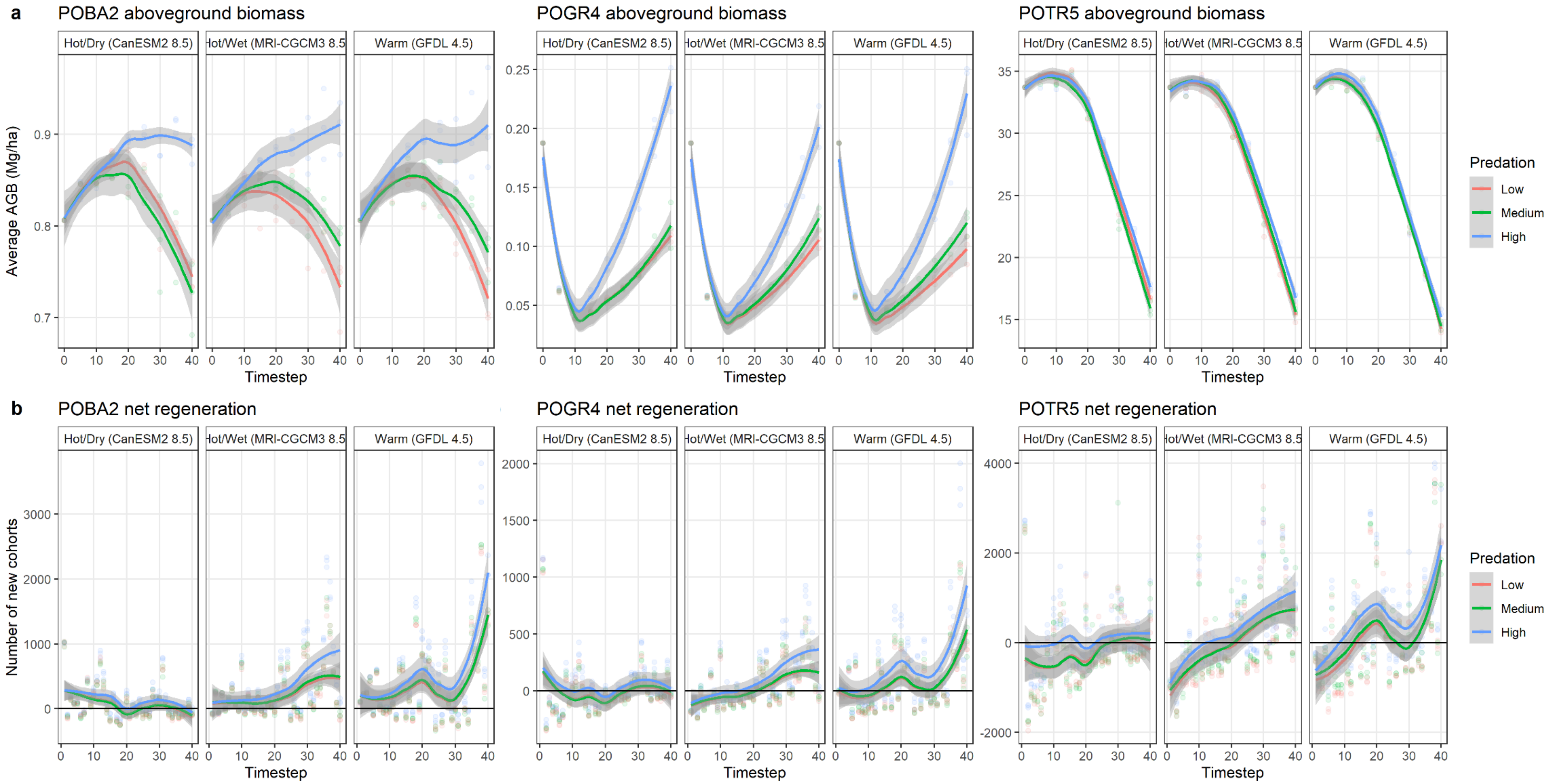

Figure 6: Projected trends in a) aboveground biomass and, b) net regeneration for balsam poplar (*Populus balsamifera*), bigtooth aspen (*Populus grandidentata*), and quaking aspen (*Populus tremuloides*) under three climate change futures and for three levels of predation intensity on moose populations from 2020-2060 on the island of Minong, Isle Royale National Park, USA.

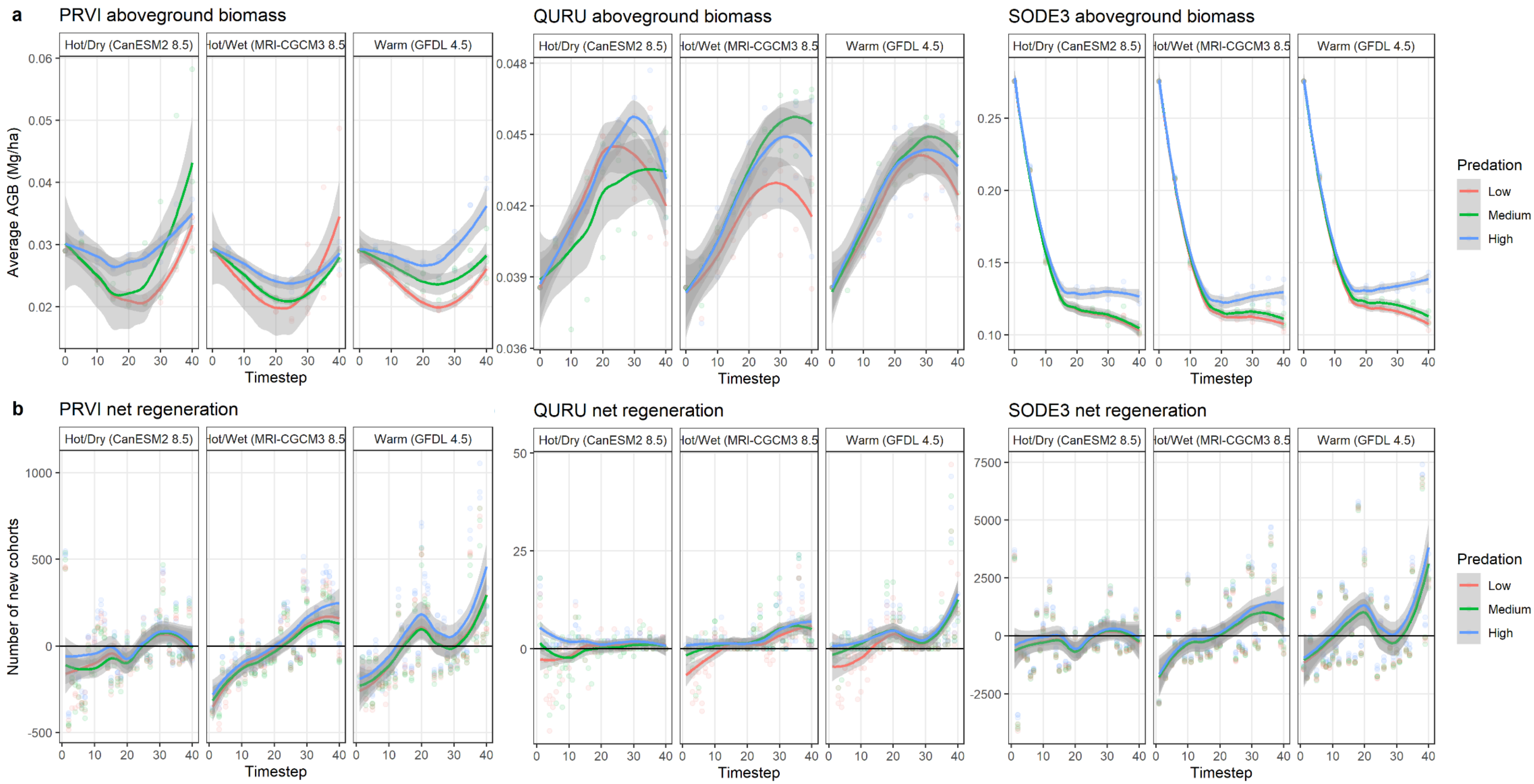

Figure 7: Projected trends in a) aboveground biomass and, b) net regeneration for chokecherry (*Prunus virginiana*), northern red oak (*Quercus rubra*), and mountain ash (*Sorbus decora*) under three climate change futures and for three levels of predation intensity on moose populations from 2020-2060 on the island of Minong, Isle Royale National Park, USA.

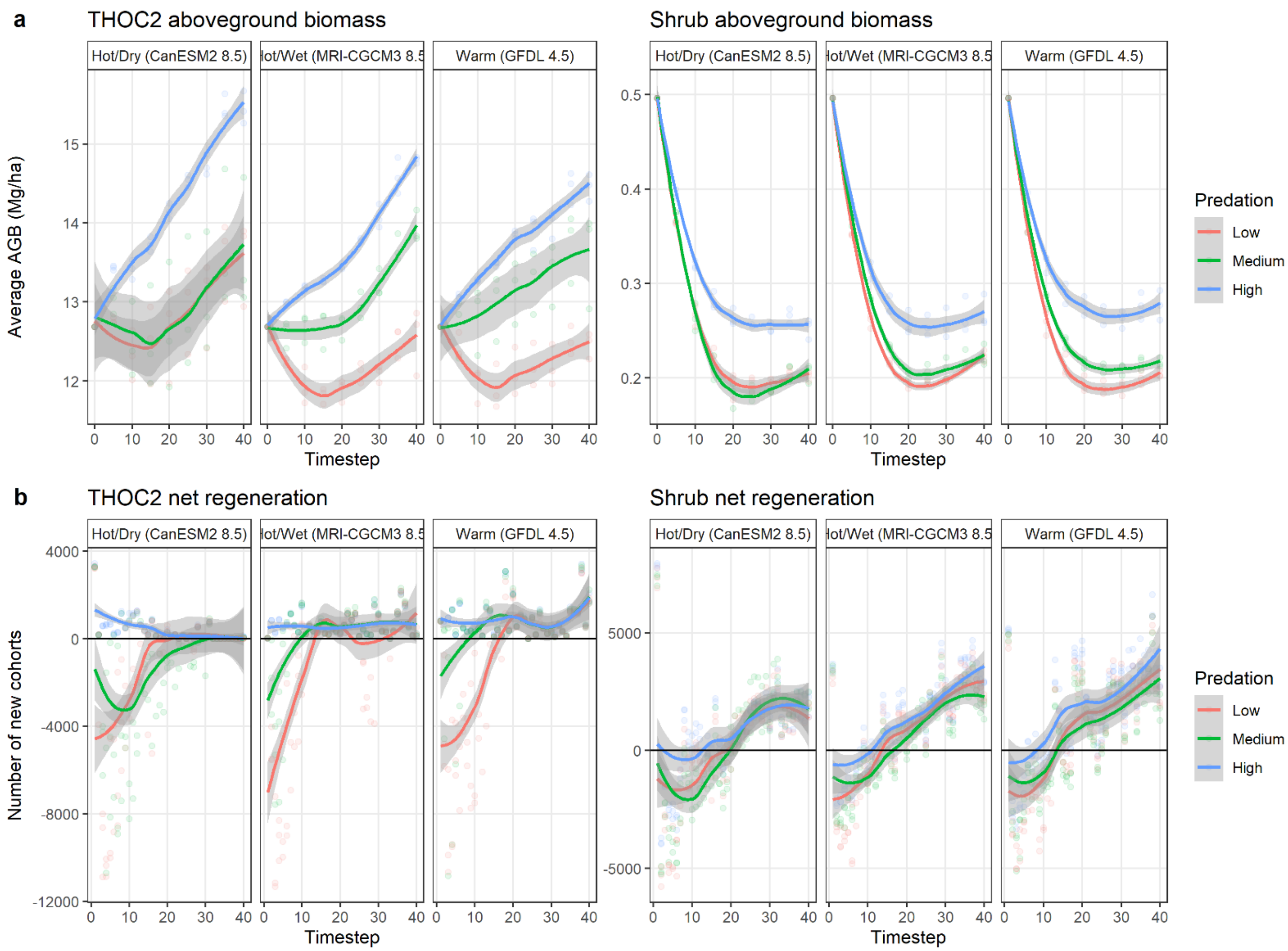

Figure 8: Projected trends in a) aboveground biomass and, b) net regeneration for northern white cedar (*Thuja occidentalis*) and shrubs under three climate change futures and for three levels of predation intensity on moose populations from 2020-2060 on the island of Minong, Isle Royale National Park, USA.

Appendix B

Table 1. Key themes about climate change and climate-informed adaptation responses derived from a series of seven semi-structured interviews with National Park Service and Grand Portage Band of Lake Superior Chippewa staff focused on impacts to boreal forest communities on Minong, Isle Royale National Park, and on Tribal trust lands.

Theme	**Code**	**Representative Quotation**
Park managers perceive climate on Minong is getting warmer and drier, which alters several ecosystems within the park. Park managers feel that other threats compound drought increase fire potential on Minong. Park managers perceive that Lake Superior is warming, which has several implications for ecological and cultural resources on Minong.	Drying rock pools	"Drought is the biggest factor in change at this point. It was really indicative today when we were at Passage Island. We have these rock pools that go along the northeast side of the island, and they were totally dried out. Drier than I've ever seen them. And so, those small, micro-habitats for species are threatened" (NPS1).
	Changing fog season Warming in-land lakes	"You know typically in the month of June, but we're at June 23rd now, we have a very dense fog season. This should be covered in fog. We shouldn't be able to see—and that might still come. I think last year was a little bit later. It came later in July. But, usually, there's a solid month where boating is really difficult, and that keeps that moisture here" (NPS1).
		"The harmful algal blooms are definitely one of the biggest impacts of climate change on the landscape. With warming in-land lake temperatures, these lakes are becoming vulnerable" (NPS1).
	Changing monsoon patterns	"We're doing a fishery study this summer and next summer that was largely prompted by some preliminary data that show we're losing cold water fish habitat in our in-land lakes and also the concern of harmful algal blooms, which is a huge management concern. That was probably prompted by the impacts of climate change and longer growing seasons and what that means for lake ecology and thermal habitat and all these things" (NPS3).
	Drought and moose herbivory	"I think the synergy between moose herbivory and drying out of the ecosystem here is something that needs for work and is really driving things like fire. As things start to open up, it's

		going to be drier and drier and we're going to have more opportunities for fire" (NPS3).
	Drought and insect defoliators	"You combine [herbivory and drought] with increased incidences of forest pests and tree death. I mean, we're just drying and drying and getting a lot more tinder on the ground to carry a fire that in the past would never have carried" (NPS3).
	Less of climate refugia	"Lake Superior acts as a giant buffer … [and it's] warming rapidly, and so, we've historically thought that it would make this almost a refugia in terms of how temperatures will change, but with how fast it's warming, I don't know if that will be the case" (NPS1).
	Lack of winter ice on Lake Superior	"[There is a] lack of ice bridges. We've already seen a downtrend in that, yet we've had these small, brief ultra cold windows where we've seen some [wildlife] movement in the last 10 years" (NPS3).
Climate change touches all aspects of land managers' jobs, even if the work is not explicitly focused on climate change. Park managers perceive increasingly strong winds which impact fire size and severity and winter storm events.	Aquatic invasive species colonization	"Beginning in 2018 I began noticing zebra mussels everywhere on Mott dock. I pull 25 or so mussels from the dock per year and they are beginning to cover shipwrecks which obscures artifacts. Although zebra mussels can't colonize right now because it's too cold; if lake temperatures increase it's over" (detailed notes from NPS2).
	Fire size and severity	"Stronger winds mean ability to carry fire, which is what happened on the Horne Fire. That thing skunked around for a week or more and then we got a 30-mile-per-hour wind, and it pushed it up into the canopy and over the ridge" (NPS3).
	Winter storm events	"High winds in winter storms are causing large waves which can erode archeological sites" (detailed notes from NPS2).
Grand Portage band staff perceive that climate in Grand Portage is warming which has numerous impacts on Tribal trust lands and management priorities.	Warming in-land lakes	"We have lakes in this region that are called cold water obligate lakes, but they have cold water temperatures and the fish species that live in them require cold water temperatures. We've already seen a loss of some cold-water species of fish in Grand Portage. We had a lake that historically was a brook

		trout lake; water temperature got so high that brook trout can no longer survive in that lake" (GPLSC3).
There are several physical and institutional barriers that make climate change adaptive amphibian conservation within the Black Ridge Canyons difficult.	Lack of winter ice on Lake Superior	"We don't much ice up here anymore. I drive up and down the highway and how much ice I've seen—it's really not much … We hardly had any ice last year. What happens is that ice develops … but as soon as you get a wind shift and wind action, it breaks the ice up and then it shifts again and then it's gone. So, we don't usually see it for a long period of time" (GPLSC1).
	Lack of ground freezing	"A lot of logging in this part of the state is dependent on the ground freezing…things aren't freezing as much…And I guess we're adjusting to that. Every year we have less and less winter wood as we experience these issues with the ground not freezing down good enough" (GPLSC1).
	Lack of ground freezing impacts moose forage	"We're having a harder time harvesting some of these areas and then over time that's going to reduce the amount of acres that we can provide forage for moose, because we need to do some amount of harvesting to maintain moose forage" (GPLSC2).
	Climate change is causing a decline in moose population	"We're seeing decline in the reservation moose population. It started about twenty years ago and all of the factors that are driving moose decline are driven by climate change (GPLSC3).
	Lack of understanding about what is acceptable in wilderness	"First of all, our habitat and our landscape is changing so that the species moose rely on for forage are changing over time" (GPLSC3).
	Leery about litigation	"With high adult mortality from brainworm and high calf mortality from wolf predation, both of which were driven by climate change, our moose population is declining" (GPLSC3).
Grand Portage Band staff perceive that extreme weather events are happening more frequently.	Changing fire seasons	"I think we see more extremes. This year was actually a perfect example. We were in fire danger and then all of a sudden we were growing web feet and then all of a sudden we got back into fire danger. It was a really strange thing" (GPLSC1).

	Stronger winds	"The wind has been stronger over the last five or six years. We're trying to clear roads more often. We were seeing a lot of power outages which is kind of a wind indicator" (GPLSC1).
	Impacts to subsistence	"We're seeing these really high peak rain flow events. We had a bridge blow out two years ago…and then Band members have a harder time getting back there to go hunting. That's a problem. We have a harder time getting back there to maintain some of those areas…and improve them for moose. There are all these cascading effects, right?" (GPLSC2).
Maintaining opportunities for subsistence and cultural connection for Tribal members is at the center of all Tribal climate adaptive work	Subsistence is a priority	"My responsibilities on the reservation are to make sure that we have subsistence foods available. So if climate change has impacted the environment such that some of those subsistence foods aren't present, you know, we only have three lakes on the reservation, and if all of a sudden one of them becomes fishless, then I'm not doing my job right" (GPLSC3).
	Directing subsistence systems	"[Brook trout] basically became extinct, and as a climate change adaptation strategy, we decided to stock yellow perch and walleye in that lake because they can survive in the higher water temperatures that we now see in that lake" (GPLSC3).
	Managing for climate resilience and subsistence	"If you plant at intentionally lower densities with wider spacing, as we hit these dry patches, they're more resilient because each tree has a little bit more resource to go from, so they can withstand drought better…One of the things we've figured out is…if we go at the real low end of density, when we go in there and release…that makes for good moose forage" (GPLSC2).
	Preserving cultural connections	"We were gifted some birch seeds from a tribe in Wisconsin because they said their birch is not doing so hot. Basically, they said, 'could you take care of our relative for us?'…So we're trying to grow out some of those seedlings and plant them so that we way we're going to have a hopefully bigger, more diverse gene pool of paper birch that are from more southerly

		climate zones and maybe have a little more adaptation" (GPLSC2).
	Minong is a climate change mitigation strategy	"I feel like if there's somewhere where things are going to change more slowly, it's probably Minong. And so, again, that's where it becomes re-establishing those connections and the ability to harvest out there again becomes part of the overall climate change mitigation strategy" (GPLSC2).