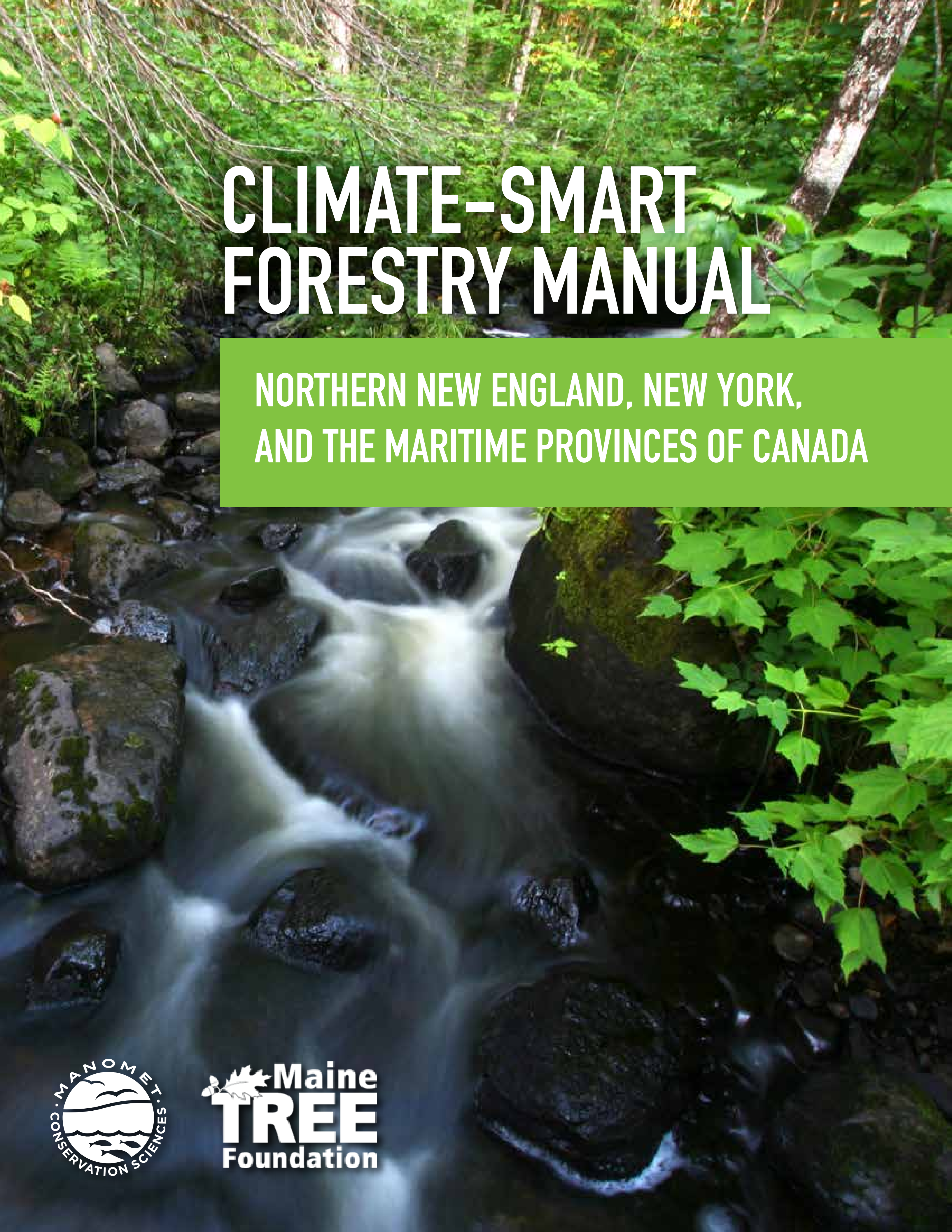

CLIMATE-SMART FORESTRY MANUAL

NORTHERN NEW ENGLAND, NEW YORK, AND THE MARITIME PROVINCES OF CANADA

MANOMET CONSERVATION SCIENCES

Maine TREE Foundation

PREFACE

In 2022, the Sustainable Forestry Initiative (SFI) released an updated Forest Management Standard with a new Climate Smart Forestry Objective. This new objective aims to ensure that forests certified to the SFI Forest Management Standard contribute to addressing climate change. To support SFI certificate holders in meeting this new objective, the Maine TREE Foundation, in collaboration with Maine SFI Implementation Committee and Manomet's Climate Smart Land Network (CSLN) developed a climate-smart forestry (CSF) manual for the Northeast (Maine, New Hampshire, Vermont, upstate New York, and the Atlantic Maritime provinces of Canada).

In the first quarter of 2023, a survey of forest managers and certification specialists identified the most common forest risks associated with climate change and the most suited management actions to address these risks. This information informed and guided the development of this CSF Manual. While there are many resources available to forest managers and companies to evaluate the impacts of climate change on forests—this manual synthesizes climate change projections, effects, and solutions through a lens of climate-smart forestry. Dealing with the risks of climate change, especially in the Northeast, is challenging and there is no standard set of actions or practices for managing many of these risks. Thus, this manual does not take a prescriptive approach. Instead, the latest science is presented for practitioners to select and apply the appropriate adaptation and mitigation measures for managing climate change-associated risks.

This manual provides supplementary information and examples of voluntary actions and is not intended to be used to develop new regulations, set standards, or develop state-based best management practices. Applying any climate-smart activity requires the consideration of specific conditions and climate impacts, which involves the professional judgment of forest managers and landowner input.

This manual was developed with guidance from members of the SFI Implementation Committees in Maine, New Hampshire, New York, and Vermont, including CSLN member companies with landholdings in the Northeast, New Brunswick, and Nova Scotia. We are thankful for the peer reviewers who provided valuable feedback. The work and consultation of past Manomet/CSLN staff members Eric Walberg, Jen Shakun, Si Balch, and Neil Williamson also provided the groundwork for this document. Christy Carovillano provided analysis and visualization support. SFI staff members Dr. Darren Sleep, Monika Gurzenski, and Nadine Block provided technical editing and design support. SFI, the company members of the CSLN, and Manomet provided financial support.

Manomet Climate Smart Land Network
Maine TREE Foundation
Maine SFI Implementation Committee
Sustainable Forestry Initiative (SFI)

EDITORS

Dr. Eric Walsh, Manomet
Andrew Whitman, Manomet

PROJECT TEAM

Logan Johnson, ME TREE Foundation
Pat Sirois, ME SIC
Dr. Eric Walsh, Manomet
Andrew Whitman, Manomet

HOW TO USE THIS MANUAL

This manual is designed for forest managers and certification managers. It helps identify climate-smart forestry (CSF) approaches to address the most concerning risks identified in the 2023 survey of the regional forestry sector. It is not necessary to read the manual in its entirety for it to be useful. Instead, based on your management needs, select the section most applicable to you.

In Section 1, you will find an introduction to climate-smart forestry and how it can be applied in both forest and business management settings.

Section 2, which is written with certification managers in mind, reviews seventeen key forest certification topics related to climate-smart forestry, identified in the SFI Forest Management Standard. It focuses on actions that can help maintain, improve, or increase the mitigation potential of managed forests, forest productivity, forest resiliency, and the production of wood fiber and other valued ecosystem services in the face of climate change. It identifies general sustainable forest management actions that are effective for building resilience to any forest threat, including climate change.

Section 3, which is written for forest managers, reviews risk factors that emerged from a 2023 survey of forest managers and certification specialists and the literature. For each risk factor, the following are provided: the survey response, a synopsis, impacted forest types, projections, and a climate-smart assessment.

Section 4, which is written for forest managers, discusses management actions aligned with a climate-smart forestry approach. These management actions are a mix of those identified from the survey and the literature.

Appendix A is a table of Major silvicultural strategies used to manage forests in New England, New York, and the Atlantic Maritimes *(Adapted from Duncker et al 2018)*

Appendix B is a table of forest carbon tools and other relevant information.

Appendix C is a visualization of the 2023 survey responses of forest and certification managers on the actions and practices that could be considered climate-smart. It provides insight into how the forestry community applies CSF actions and identifies additional CSF actions.

As you use this manual, keep the following in mind, especially regarding any listed actions:

The manual focuses on key climate change risks identified by foresters and managers and key forestry objectives identified by SFI. Other environmental and forestry manuals, silvicultural guides, and state water quality best management practice (BMP) manuals are also referenced. This manual is designed to be used alongside the mentioned materials, not to replace them. They can be used together to apply climate-smart actions.

Applying all the practices and/or actions in this manual to every acre will not be possible or necessary. Landowners across the region will vary in their goals and capacity (i.e., “scope and scale”), forest vulnerability and risk level, and access to resources that help achieve climate-smart objectives. Each landowner will develop a customized climate-smart forestry strategy, and this diversity of management can improve the resilience of the sector and regional forests.

Many recommended actions may conflict with other recommended actions in certain circumstances, but understanding landowner objectives and forest ecosystem dynamics under climate change will help resolve conflicts and prioritize actions.

Finally, the forest types, associated species, and vulnerabilities mentioned throughout the manual are from Janowiak et al. 2018.[1] Vulnerabilities identified in that report were compared to the survey results, and the risks in agreement between the two were included in this edition of the manual. For additional information on forest vulnerabilities and the adaptive capacity of the Northeast, please refer to these references: Janowiak et al. 2018 and Swanston et al. 2018.[1,2]

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SECTION 1

INTRODUCTION TO CLIMATE-SMART FORESTRY

ERIC WALSH AND ANDREW WHITMAN

1 | INTRODUCTION

1.1 WHAT IS CLIMATE-SMART FORESTRY?

Climate-smart forestry (CSF) refers to the management of forests that promotes climate change mitigation, adaptation to climate change effects, and the conservation of ecosystem benefits. It recognizes forests' critical role in regulating the global climate and the multiple benefits they provide to society. Many sustainable forestry actions are already aimed at increasing forest productivity and resilience but may not specifically reduce the impact of climate change on managed forests.

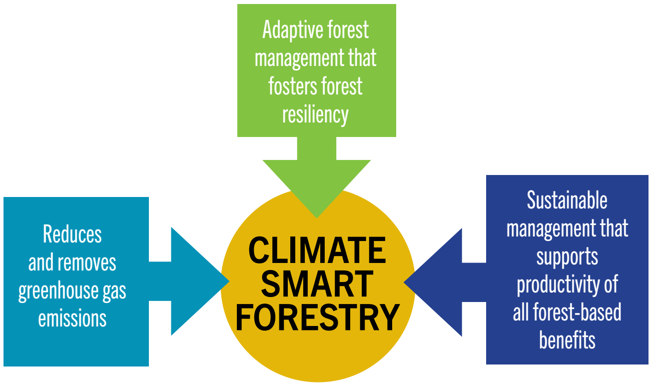

Figure 1. The climate smart forestry framework. Adapted from Chizmar and Parajuli (2022). What is Climate Smart Forestry? A Brief Overview. North Carolina State Extension. https://content.ces.ncsu.edu/what-is-climate-smart-forestry-a-brief-overview.

Forests are essential for mitigating climate change because they sequester carbon from the atmosphere and convert it into long-term storage. CSF approach promotes mitigation activities that aim to optimize carbon sequestration, optimize landscape and wood product storage, consider carbon substitution, and minimize greenhouse gas (GHG) emissions. One of the most effective ways to achieve this is through sustainable forest management, which involves carefully planning and monitoring forest resources to ensure long-term productivity and health.

The mitigation potential of forests is only realized if forests are managed to be resilient to risks caused or amplified by climate change – climate adaptation. These include the increased frequency and severity of wildfires, droughts, pests, and other disturbances. By implementing adaptive forest management – such as promoting the growth of resilient tree species, improving forest ecosystem processes, reducing the effects of disturbance events, and increasing forest accessibility for management interventions (both silvicultural and protection responses) – these risks can be minimized. Thus, need for risk management is inversely related to the capacity of forest ecosystems to sequester and retain carbon while conserving other ecosystem benefits like wood fiber production, water regulation, and biodiversity.

An increased demand for wood fiber and ecological benefits from forests points to a need to intensify part of forest production. To meet these demands and avoid habitat conversion, the leakage of GHG, and the loss of ecological benefits elsewhere, managed forests need to optimize ecosystem benefits with climate adaptation and mitigation.

The CSF approach (i.e., the integration of Mitigation, Adaptation, and Delivery of Ecosystem Benefits) requires an enabling environment if it is to be successfully applied. In sustainable forest management, an enabling environment can refer to the scientific, social, economic, and political conditions that support implementing and scaling up sustainable practices and policies. Specifically, it can involve:

- Policies and incentives for landowners and communities to adopt climate-smart practices. These include forest certification programs, federal and state funding programs, payments for ecosystem services or carbon credits, tax incentives, data development and sharing, infrastructure projects, and economic development for new and emerging climate-smart products.
- Institutions for implementation, capacity building, technical training, knowledge-sharing, and extension services. These include timber management companies, forest certification organizations, research institutions, NGOs, extension services, government agencies, and other stakeholders.
- Finance and investment opportunities for implementing climate-smart forestry practices, which often require up-front costs and long-term investments. Mechanisms such as government funds and subsidies, private equity investments, grants, and ecosystem services markets specifically targeted for climate-smart forestry initiatives help offset financial risks and scale adoption of the CSF approach.
- Research, innovation, and the transfer of emerging technologies to the marketplace, which can enhance the efficiency and success of climate-smart forestry. Research institutions, research networks and platforms, and supporting innovation hubs that promote the development and dissemination of climate-smart forestry technologies and practices are essential for the success of a CSF approach.
- Workforce development and a focus on a highly skilled workforce to implement and maintain emerging climate-smart technologies and land management practices.

The enabling environment components are interdependent. Workforce development requires higher education institutions and technical programs to prepare the workforce with the requisite skill level to meet the demands of timber management companies. These companies will depend on emerging technologies brought to market through small business development and initially developed through use-based research supported by public and private funds. Essentially, the enabling environment provides an integrated support network that promotes and maintains the application of a CSF and increases the cost-effectiveness and scalability of the CSF approach.

CSF will be critical for addressing climate change and promoting social and ecological sustainability within commercial forestry. Implementation success requires companies to devise management actions that integrate climate change mitigation, adaptation, and continual delivery of ecosystem benefits while simultaneously leveraging and supporting the enabling environment.

1.2 CLIMATE-SMART FORESTRY APPROACHES

1.2.1. Business

Timber management companies operate within the *Institutional* component of the enabling environment for CSF. The role of a company, within the context of CSF, is to generate external and internal functions that promote, support, and enhance the implementation of CSF land management. Companies may need to consider actions beyond the existing key forest management actions. The company's role is to understand how a CSF approach operates and integrates with its land management philosophy and what is necessary to make it a success.

This requires companies to operate at different scales, identify the land management practices and the management system necessary to support their application, and fully leverage the benefits that can come from the CSF approach. For example, producing wood fiber under a management prescription that mitigates wildfire fuel loads and increases stand resiliency to wildfire events is climate-smart compared to a business-as-usual approach that does not address elevated or increased wildfire risks. A company may need the ability to identify and implement those practices, evaluate different scenarios of fuel management and estimate the changed outcome (e.g., decreased carbon emissions from a decline in wildfire risk), leverage emerging climate-smart commodities markets to monetize the improved forest management practices, monitor ecosystem conditions (e.g., fuel loads, forest growth), and respond to changes in conditions that threaten ecosystem function and projected outcomes.

External functions include sourcing, identifying, and/or otherwise leveraging external information, financial resources, and emerging markets that support adopting and implementing a CSF approach.

Internal functions focus on building an adaptive climate change capacity that improves the business model and management of the forest company, which is not the same as changing forest management practices focused on forest ecosystems. Addressing climate change may require reevaluating key assumptions that underlie forest management and institutional models.

Companies can leverage CSF to increase their resiliency to climate change. Resiliency has three key attributes: *buffer capacity, adaptive capacity,* and *transformability*.[3] This framework emerged from the dairy industry with a foundation in the ecosystem, organization, and farm management research. The resilience of a forestry organization is the capacity to respond to a change in condition (e.g., environment, markets) and return to baseline or leverage the opportunities that arise.[4]

Resiliency starts with *buffering capacity*, which is the ability to respond to small changes in environmental or business conditions that require proportional changes in operational tactics and strategies. Typically, these events are within the scope of expected variability, and the organization has prepared for them. *Adaptive capacity* is for extreme events caused by changes in underlying environmental conditions; examples may be stand-replacing fires that emerge from persistent drought. These events are rare, but still plausible under the expected range of variability. The assumption for buffering and adaptive capacity is that the disturbance does not cause a permanent shift in land management or business outcomes.

Within the context of CSF, example actions related to improving buffering and adaptation capacity abilities are:

- Mitigation
  - o Plan harvesting to achieve the carbon goals for each stand.
  - o Develop a program to identify and address GHG emissions within your company's operational control.
  - o Apply avoided forest conversion policies by enrolling forest land in current-use taxation programs, state or federal conservation programs, easements, etc.
  - o Provide training or incentives to loggers to improve wood merchantability and grading into longer-lived products during harvest and processing.
  - o Assess forest carbon for carbon offset market opportunities.
- Adaptation
  - o Identify and prepare for regional- and/or stand-level climate change risks and vulnerabilities.
  - o Implement periodic forest inventory updates and recalculations of planned harvests when climate and related factors affect productivity.
  - o Develop climate change adaptation strategies that integrate resistance (maintain current forest), resilience (recover forests to former conditions), or facilitated transition (manage for future forests) principles.
  - o Systematically apply road management practices to reduce the impacts of extreme rainfall events or improve their effectiveness as fire breaks.
  - o Explore markets for increasing merchantability and grading of underutilized species and low-grade wood into longer-lived products.
- Ecosystem Services
  - o Use federal, state, or provincial water quality best management practices which have been updated to address climate change.
  - o Maintain a network of habitat corridors to support species range shifts in response to climate change.

There are additional general practices that build capacity for the overall CSF approach; these include systemically keeping abreast of climate change science information related to forest management and assessing climate-change-related business risks and vulnerabilities.

Transformability addresses complete shifts in underlying environmental and business conditions that cause current operational systems and approaches to be inefficient or ineffective. Companies should evaluate if transformational adaptation – the revision, modification, or replacement of existing strategies and norms – is necessary.[5] This is determined by assessing risks and vulnerabilities resulting from current practices, systems, and processes. For example, the development of an assisted species migration program may be necessary when the regeneration of a particular species or plant functional type fails due to changes in temperature and precipitation that are outside the normal range of a species' niche tolerance. Or promoting the development of tax credits aimed at introducing processing plants using emerging technologies for low-grade wood.

A CSF approach benefits from a company identifying its capacity for resilience and addressing the gaps and opportunities that arise. The CSF Adaptation pillar concentrates on managing the forest's ability to adapt to environmental changes. However, when implementing a CSF approach to forest management, the company must also develop the capability to adapt to change. Implementing a CSF adaptation approach to business management can enhance a company's capacity to adjust to climate change.

1.2.2. Forest Management

A diversified management approach, from the stand to landscape levels, can increase the adaptive capacity of forests to climate change. It involves managing forests to resist or build resilience to disturbances such as wildfires, pests, disease, drought, wind, and heat while supporting the transition of parts of the forest ecosystem to new states and conditions better suited to a changing climate. The approach involves three main strategies: *Resistance, Resilience*, or *Transition (RRT)*:

- *Resistance:* To increase the capacity of forests to remain relatively unchanged when impacted by a disturbance event. One example related to wildfire resistance is fuel reduction, which can include thinning, prescribed burning, and other fuel reduction treatments. It also can involve promoting genetic diversity and using disease-resistant tree species to reduce the risk of pest and disease outbreaks. Resistance management can become cost intensive as climate change persists and environmental conditions shift towards more novel conditions. Thus, it is most beneficial for short-term objectives or the protection of high-value resources.
- *Resilience:* To accommodate change while facilitating a post-disturbance recovery that produces ecosystem conditions similar to the pre-disturbance state (i.e., a similar delivery of ecosystem benefits). This involves promoting forest conditions and diversity by maintaining a mix of age classes and species adapted to the various conditions that may emerge post-disturbance. It also involves maintaining and enhancing the natural processes that support forest ecosystem functions, such as nutrient cycling, water cycling, and carbon storage, which will aid in forest recovery. Like resistance, the cost-benefit balance will likely shift as environmental conditions change.
- *Transition:* To support the transition of forest ecosystems to new states and conditions better suited to a changing climate. This involves guiding forest trajectories in a way that allows them to adapt to changing climate conditions, such as warmer temperatures, altered precipitation patterns, and more frequent and severe disturbances. This may involve promoting non-dominant species or establishing new tree species better adapted to shifting environmental conditions, changing silvicultural practices to promote natural regeneration, and promoting the natural migration of tree species.

Overall, the RRT approach involves managing forests to increase their climate change adaptive capacity. It recognizes that forests are complex systems influenced by various factors, including climate, topography, soils, and interactions with other organisms. It seeks to manage forests to promote their long-term ecosystem function and ensure the delivery of benefits.

Silvicultural practices provide the tools for implementing the RRT approach. The practices best suited for climate change adaptation deal with the stressors influenced by climate change that pose the most significant risks to forest ecosystems.[6] Such stressors (e.g., heat stress, soil moisture deficits, pest infestation, and invasive species) affect different processes at different scales (e.g., tree physiology and stand dynamics), and understanding those mechanisms and implementing appropriate actions can mitigate forest vulnerability.

General silvicultural strategies, such as density and composition management, weed control, site preparation, genetic improvement, and threat reduction, facilitate RRT and climate change adaptation.[6] Balancing stand resource availability and utilization is a long-standing practice that will be more imperative as site conditions shift under climate change. Density management can balance site resources by modifying species composition and stand structural features that influence climate-related stresses.

1.3 FOREST MANAGEMENT RELATIONSHIPS

CSF can fit within the frameworks of other landscape-scale forest ecosystem management approaches. The Triad system is a landscape-scale forest management approach based on three components: (1) intensive plantation management, (2) ecological forest reserves, and (3) a continuum between intensive and reserve management based on ecological/extensive management forestry.[7,8] Like the Triad model, CSF management seeks to achieve wood fiber requirements at the landscape scale and other ecosystem benefits such as biodiversity and water quality and quantity. Like the Triad model, CSF also seeks to balance the delivery of ecosystem services. Like the CSF aproach, the Triad model can also produce mitigation and adaptation outcomes.

Landscapes subjected to both intensive and ecological forestry management have the ability to sequester greater levels of forest carbon, i.e., CSF mitigation.[9] In addition, the inherent landscape diversity that is created by applying the Triad model is also an adaptive strategy for minimizing the impact of a catastrophic event[8] related to climate change. Conversely, the RRT approach of climate-smart forestry adaptation would complement the Triad model by applying actions to improve the resilience of each component (intensive forestry, reserve forestry, and ecological/extensive management).

CSF is related to other forest landscape management models and can complement or enhance an existing one. The objective would be to identify the additional or synergistic outcomes that emerge by integrating the CSF approach with existing landscape management models already used by landowners. CSF does not need to replace or reinvent the existing organizational approaches; it will likely enhance their outcomes.

1.4 EXISTING CSF ACTIVITIES

In the Northeast, the New England Forestry Foundation (NEFF) is leading a five-year project to pilot a climate-smart commodities initiative. The program intends to demonstrate CSF on 80k acres across New England. The program's three goals are to incentivize the adoption of CSF practices, build markets for mass timber (i.e., climate-smart commodity), and implement robust carbon monitoring and verification to ensure the carbon in the terrestrial ecosystem and harvested wood products (HWPs) is correctly accounted for. For more information, please visit NEFF's website.

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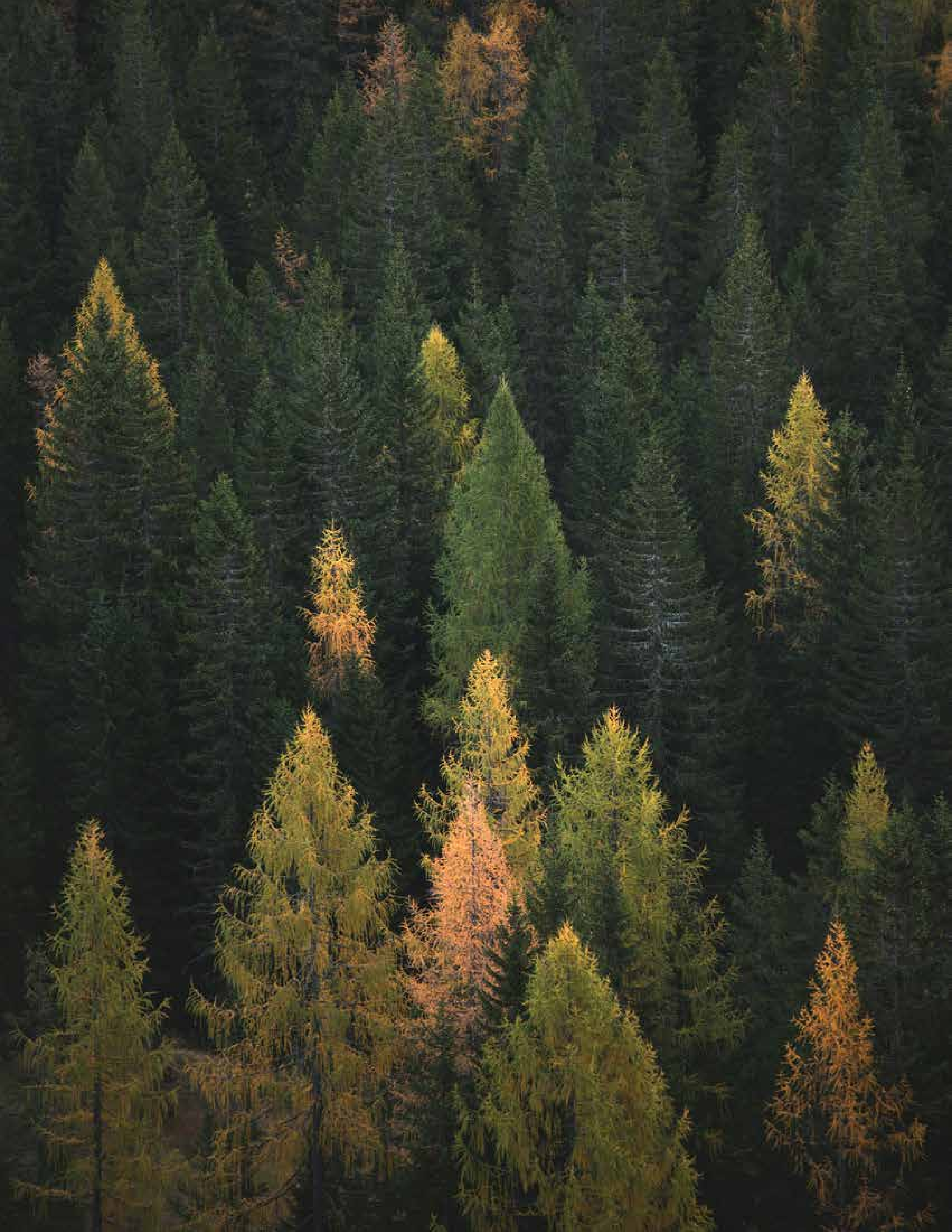

SECTION 2

CLIMATE-SMART FORESTRY ACTIONS FOR 17 SUSTAINABLE FORESTRY TOPICS

ERIC WALSH AND ANDREW WHITMAN

2 | INTRODUCTION

This section provides commercial forest land managers and certification managers with practical information about company practices that can help them apply the principles of climate-smart forestry to managed forests. Actions in this section refer to company practices (e.g., strategies, policies, programs, processes, and plans) used to conduct forest management. This section focuses on actions unique to climate-smart forestry, because many general sustainable forestry actions are well described elsewhere in forest stewardship and silvicultural guides for the region and are already well-known to many forest managers.

Each of the following 17 sections discusses a specific SFI Forest Management Standard Objective, and uses the following format

- *Background:* This section provides a general summary of SFI certification requirements so that the reader understands the topic's scope and how it might have a climate-smart forestry component.
- *Climate Change and [Topic]:* This section summarizes relevant science points to help the reader understand how climate change affects the topic (e.g., forest health) or might affect management (e.g., continuous improvement). It also provides science-based information to inform readers how to select and apply climate-smart actions. This section cross-references other topics when appropriate.
- *Climate-Smart Considerations for [Topic]:* This section identifies other practical user considerations when applying actions. This section varies greatly from topic to topic.
- *Climate-Smart Actions:* This section is composed of two types of actions that can be used to (1) help recognize existing actions that are climate-smart and (2) adopt climate-smart actions in the future. Readers should always consider landowner objectives, management unit conditions, practicality, and effectiveness before adopting climate-smart actions. Actions were selected from the scientific literature and were ranked by certification managers and foresters for their use and effectiveness and based on their recommendations. The actions lack qualifying words such as "when possible," "as appropriate," and "if practical" because actions in this manual are not possible, practical, or appropriate to all situations. They require professional judgment to apply.
    - *Favorably Ranked Actions:* This section lists climate-smart forestry actions from the scientific literature that were favorably ranked by company forest management staff. Favorably ranked actions were actions that were (1) either identified as “Likely” or “Very Likely” to be recommended, (2) rated as “Good,” “Very Good,” or “Excellent” in their effectiveness, and (3) recognized as “Somewhat” or “Substantially” already applied. Forest managers can have some confidence in these actions, as peers have tested them and determined them to be relevant, functional, and practical.
    - *Other Actions:* This section lists climate-smart forestry actions from the scientific literature that (1) were less favorably ranked by company forest management staff in the region in a survey and (2) were recommended in peer-reviewed literature but have yet to be tested on commercial forest land. Hopefully, readers will be stimulated to create and apply practical and useful actions after reviewing this range of practices.
- *Resources:* This section has a short list of practical references for applying listed actions. Each reference has a brief annotation to help readers select references most suited to their needs.

2.1 FOREST MANAGEMENT PLANNING

Background:

Forest management planning is essential to ensure long-term sustainable harvest levels and help reduce the conversion of productive forests to other uses. It identifies landowners’ goals and objectives, plans management activities to support them, and ensures long-term forest health, productivity, and ecological benefits (e.g., carbon storage, water quality, biodiversity) for future generations. The three key objectives of climate-smart forestry – mitigation, adaptation, and intensification – can be incorporated into landowner goals, objectives, and activities during the forest management planning process.

Climate Change and Forest Management Planning:

Rapid changes in carbon markets, investor and supply chain interest, public climate policy, and climate have made climate change an essential consideration for forest management planning. Climate adaptation is vital to reduce climate risk for the value and productivity of forestland and increase forest ecosystems' resilience for other benefits. The planning process can integrate adaptation plans to help forests be climate resilient.

Landowners can prepare for climate change by using existing information to assess the threats posed by forest disturbances (e.g., wind, pest species) that are made worse by climate change and identify strategies to reduce the climate risk of forests and road networks. For example, the northward range expansion of native and non-native pests and pathogens is affecting tree health and mortality, and landowners report that extreme rainfall disrupts road networks and the ability to operate in the forest. The planning process should consider whether these increased risks affect silvicultural management and harvest operations and whether they require any change in management, an increased application of existing practices, or the adoption of new practices.

The planning process can also integrate mitigation plans to help identify future options for managing forest carbon and mitigation potential. This can leave open future opportunities with investors, markets, and offset projects, given that demand and prices for forest carbon offsets are increasing. Mitigation potential can also be maintained by avoiding forest conversion. It also requires consideration of the uncertainty around climate impacts on forests and markets, especially with changes in carbon markets and supply chain requirements.

Climate Change and Forest Composition:
Models project that tree species ranges and forest types will shift with climate-change-related changes. Sugar maple, American beech, and eastern hemlock – all long-lived, shade-tolerant species – are expected to remain stable or gain relative biomass in the next few decades. On the other hand, red spruce and other northern temperate species, such as balsam fir and paper birch, may be increasingly sensitive to warming temperatures and increasing evaporation rates, which reduces their seedling/sapling recruitment rates. They may be beginning to decline and shift ranges in the next few decades.

Some simple modeling efforts suggest that the inertia associated with the long-term forest dynamics of present species may slow tree species range shifts driven by climate change. Some tree species (e.g., multiple ash species, balsam fir, eastern hemlock, American beech) will likely experience high mortality rates as invasive pest species shift their ranges north with warming. Climate change may not significantly affect the current regeneration of other species or overall forest composition until mid-century. Tree mortality may or may not increase substantially, so harvest planning may not significantly change for stands where tending treatments (e.g., commercial thinning operations) are applied. Planning for pre-commercial thinning and regeneration treatments may need to consider which tree species will be crop trees suitable for harvest as climate conditions change in the next 40 to 80 years.

Planning for Climate Change:
Adaptive Actions: Three types of adaptive management actions are options for stand and landscape management in the face of climate change: resistance, resilience, and transition.

- *Resistance* actions focus on maintaining or restoring forest conditions to produce wood fiber and other benefits. Such actions could include making additional investments to reduce pest-related risks to high-value plantations.
- *Resilience* actions help ensure that forests can regenerate and maintain a closed canopy. Such actions could include conducting pre-salvage harvesting to replace eastern hemlock that is at risk from the hemlock woolly adelgid (HWA).
- *Transition* actions involve helping forests adapt to projected conditions. Such actions could include planting seeding provenances suitable for future weather conditions.

These three types of actions can be used to develop a portfolio approach to climate-smart forestry – though the effectiveness of resilience and transition actions have yet to be well tested at large scales. In a portfolio approach, planners and forest managers can consider landscape and stand-level risks when using one of these actions. Moreover, the portfolio can vary over time. Current planning may include resistance actions, but as climate change advances, resilience and transition actions might be given greater weight based on observed climate change impacts, available forest types, and other local conditions.

Integrating Adaptive Actions with Landscape Strategy: Landowner objectives and forester expertise will determine the range of different silvicultural strategies and actions used to manage climate risk (See table 1, Appendix A). The nature of climate risk for each silvicultural strategy will likely vary by regional climate and disturbance regimes, forest type and age (e.g., natural community type), and its general susceptibility to different abiotic and biotic disturbances such as drought response (influenced by soil moisture index and soil type) and wind throw risk (influenced by topographic position). It is unlikely that any single silvicultural strategy can achieve all landowner goals for wood fiber production and forest resilience. Each silvicultural strategy has a different combination of practices that can be used to reduce specific climate risks. No strategy can eliminate all climate risks, but the planning process can identify strategies to manage climate risk and achieve management objectives. Monitoring can help managers identify the effectiveness of different strategies.

Climate-Smart Considerations for Forest Management Planning:

- *Scope:* Forest managers cannot control the magnitude and timing of climate impacts, though they can reduce climate risk exposure. Before planning for climate change, forest managers should practically consider how much control they have over different climate impacts, those already occurring (e.g., increased frequency in extreme rainfall events) and projected to occur over the planning time horizon (e.g., range expansion of pest species as winters become warmer).
- *Uncertainty:* Many essential forest resources may have relatively low or highly uncertain climate change risks for the forest management planning period, requiring little or no attention. Forest managers should prioritize certain, manageable, near-term risks (e.g., extreme rainfall on road systems, balsam wooly adelgid) over uncertain, long-term ones that cannot be easily managed when planning climate change adaptation approaches (e.g., compositional changes in northern hardwood forests). This will ensure effective risk management.
- *Near-term vs Long-term:* Current summaries of climate change impacts can contain an overwhelming amount of information. Near-term impacts are smaller than long-term impacts. Over time, the range of projected impacts and uncertainty increases, which may require additional monitoring to detect and respond promptly to change. As a result, forest managers should generally prioritize addressing near-term impacts, since they are both more certain and more manageable.
- *Planning Horizons:* Consider planning horizons for different types of operations. For example, the planning horizon will differ for road building (0 to 5 years), harvest operations (5 to 20 years for thinning, selection harvests, and first shelterwood entries), and regeneration operations (40 to 80 years for final shelterwood entry, clear cuts, and planting). Different planning horizons determine your data and information needs. Road-maintenance plans probably should focus on recent weather

trends and current experiences, but road upgrades may also need to consider climate projections for the mid-century (2040–2060).

- *Landowner Context:* Planning should be designed to meet owner needs, reflect the financial resources available to reduce climate risks, and consider the level and certainty of climate risk to essential forest resources—especially wood production (**SFI Objectives 1 and 9**).
- *Ecosystem Benefits:* Climate change risk may require incorporating climate-smart forestry planning into management for key forest ecosystem benefits, including wood production, forest health, water resources, biological diversity, unique cultural and geological values, recreation, visual values, resources for which Indigenous Peoples have rights, and fire resilience **(SFI Objectives 2 through 6, 8, and 10).**
- *Communication and Training:* Climate change risk may require incorporating climate-smart forestry into planning for education and training, including investments in forestry research, information used in the training and education of company foresters, and information shared during engagement and outreach activities aimed at local communities and family woodland owners (**SFI Objectives 12, 13, and 14).**
- *Governance:* Climate change risk may require the incorporation of climate-smart forestry into planning for the efficient use of fiber resources, achieving legal and regulatory compliance if the regulatory environment is changing, managing any public land responsibilities, communicating and reporting about forest management to the public, and reviewing and continually improving management (**SFI Objectives 7, 11, 15, 16, and 17).**
- *Using Available Data:* Projected range shifts due to climate change are available for tree species, wildlife species, and some pest species. These results may be sufficient for assessing climate risk to trees, wildlife, and pest species. It may require monitoring or tracking government monitoring to compare predictions with forest conditions.
- *Forest Modeling:* Some empirical forest models may have options for adding climate data when projecting future forest conditions. Some mechanistic models can provide a flexible way of assessing the effects of climate changes on environmental conditions and tree growth.
- *Scenario Analysis:* Scenario analysis can assess the uncertainty range associated with projected changes in forest and tree species ranges (low, medium, high) under most scenarios. It may use existing modeling outputs or user modeling for different climate scenarios using Shared Socio-economic Pathways provided by IPCC. Scenario analyses often include a "business-as-usual" (BAU, no climate change) scenario, a low-change scenario (SPP1-SPP2, or 1.0-2.4 °C by 2100), and a high-change scenario (SPP3-SPP5, or 2.8 to 5.7 °C).

Climate-Smart Management Actions:

Favorably Ranked Actions:

- In planning, include an assessment of forest carbon for carbon offset market opportunities.
- Identify during planning the regional and/or stand risk levels for disturbances (e.g., from fire, drought, wind, key pest species) made worse by climate change.
- Identify practical strategies in plans for reducing climate-related risks to forests and extreme weather on road networks.

Other Actions:

- Adopt climate-smart forestry goals for maintaining or enhancing mitigation potential, forest resiliency, and sustainable intensification to produce both more wood fiber and more ecological benefits.
- Incorporate climate change information into modeling future forest growth yield projections.
- Identify practical strategies in plans for increasing the mitigation potential of silvicultural treatments (e.g., high-yield planting stock, long rotations, retention) and operations (e.g., reduced field time, optimized travel in road design, rewarding fuel efficiency in harvesting and hauling).
- Use landscape strategies for increasing climate resistance and resilience, such as functional zoning (i.e., categorizing zones based on forest vulnerability and management objectives), or use harvest treatments to manage diverse landscape patterns based on structure, patch size, age class, and species composition that are resilient to expected disturbance regimes.
- Identify high-resiliency areas and manage them with more resources than other areas.
- Identify low-resiliency areas (e.g., drought-, fire-, and wind-throw-prone areas) that might significantly benefit from short-rotation and/or thinning treatments.
- Describe a strategy to manage opportunities for and risks to forest management and timber production presented by climate change.
- Develop emergency response plans for extreme weather events (e.g., significant wind-throw events, widespread road washouts).
- Modify species, age, and/or structural diversity at the landscape scale to increase climate resilience in the long term ("portfolio" diversification).
- Adopt a cost-effective road improvement plan to reduce the vulnerability of road systems to excessive rain, flooding, and thawing to assure access.

Resources:

Planning for Mitigation Potential

Cameron, Ryan E., Chris R. Hennigar, David A. MacLean, Greg W. Adams, and Thom A. Erdle. 2013. A Comprehensive Greenhouse Gas Balance for a Forest Company Operating in Northeast North America. Journal of Forestry 111, no. 3: 194–205. https://doi.org/10.5849/jof.12-043 *(an example of forest company GHG emissions analysis).*

Dugan, Alexa J.; Lichstein, Jeremy W.; Steele, Al; Metsaranta, Juha M.; Bick, Steven; Hollinger, David Y. 2021a. Key data inputs and modeling outputs for "Opportunities for forest sector emissions reductions: A state-level analysis". Fort Collins, CO: Forest Service Research Data Archive. https://doi.org/10.2737/RDS-2021-0018 *(describes the CBM-CFS3 forest carbon model and provides an example of how to use existing local/state data to parameterize the model for local use).*

Dugan, A.J., Lichstein, J.W., Steele, A., Metsaranta, J.M., Bick, S. and Hollinger, D.Y., 2021b. Opportunities for forest sector emissions reductions: a state-level analysis. Ecological Applications, 31(5), p.e02327 *(describes the CBM-CFS3 forest carbon model and provides an example of how to use existing local/state data to parameterize the model for local use).*

Daigneault, A.J., Hayes, D.J., Fernandez, I.J. and Weiskittel, A.R., 2022. Forest Carbon Accounting and Modeling Framework Alternatives: An Inventory, Assessment, and Application Guide for Eastern US State Policy Agencies. University of Maine, Orono, ME *(provides a framework for forest carbon accounting and modelling under different scenarios at large scales).*

Planning for Forest Resiliency

Catanzaro, P., D'Amato, A.W. and Huff, E.S., 2016. Increasing Forest Resiliency for an Uncertain Future. University of Massachusetts, Cooperative Extension Landowner Outreach Pamphlet: Boston, MA, USA, p.32.

Ontl, T.A. et al. 2020. Practitioner's menu of adaptation strategies and approaches for forest carbon management. In: Ontl, T.A, et al. 2020. Forest management for carbon sequestration and climate adaptation. Journal of Forestry 118(1):86-101. doi:10.1093/jofore/fvz062 *(provides a concise list of adaptation actions and strategies).*

Swanston, C. W. et al. 2016. Forest Adaptation Resources: climate change tools and approaches for land managers, 2nd ed. Gen. Tech. Rep. NRS-GTR-87-2. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 161 p. http://dx.doi.org/10.2737/NRS-GTR-87-2 *(provides a process for assessing climate impacts and vulnerabilities, identify adaptation actions and practices, and monitoring).*

2.2 FOREST HEALTH AND PRODUCTIVITY

Background:

A fundamental principle of sustainable forestry is to ensure long-term forest productivity, forest health, and the conservation of forest resources by sustaining productive tree cover, reducing the risk of damaging pests, pathogens, and invasive species, and minimizing damage to soil health and residual trees. Forest managers can best ensure forest health and productivity by managing forest composition, structure, and processes so that forest ecosystems can restore themselves or readily be restored following natural or novel disturbances and forest management.

Critical abiotic disturbances such as wind and ice storms, excessive rainfall, and drought may damage or stress forests. This may make forests more susceptible to biotic disturbances such as pests, pathogens, and invasive species. Many abiotic and biotic disturbances already exist in forest ecosystems, but unprecedented abiotic events due to climate change can create new problems with existing disturbance agents.

Timber harvesting can be applied sustainably to influence a forest composition and structure that helps maintain or enhance forest health and productivity. It typically requires the careful protection of trees and soils during harvesting to minimize impacts on forest health and productivity and ensure long-term site productivity. Forest health and productivity risk declining without forest management due to fire, pests, and pathogens—so may the economic value and ecosystem benefits of forests for landowners and local communities.

Climate Change and Forest Health and Productivity:

Climate change in the next few decades is projected to increase forest disturbance and tree stress due to slightly more frequent extreme weather events and an overall changing climate, making conditions more favorable for damaging forest pests, pathogens, and invasive species. Extreme wind events, drought, fire risk, snow, and icing events are projected to become slightly more frequent and stress many tree species, especially when species are not well suited to site conditions. Tree stress is less likely for species well-suited for local site conditions. Tree spacing during planting or thinning may reduce drought stress or windthrow damage but may require careful management to be successful. Northern tree species at the southern edge of their range may more frequently face stress as temperature regimes become less suitable for these species (e.g., balsam fir in southern and central New England).

Climate change is predicted to reduce the mortality of many pest species and contribute to range expansions and more frequent outbreaks. Projected declines in the frequency and intensity of cold temperatures may increase winter survival, allowing invasive pest species like balsam and hemlock wooly adelgids to expand their range northward. Forest pathogens can also affect forest structure and composition, significantly altering forest ecosystems. Outbreaks are more likely at higher temperatures and moisture levels and are expected to increase in the next few decades. Stands with age and species diversity tend to be less affected by pest and pathogen outbreaks, but managing stands for greater age and species diversity takes decades.

Climate-Smart Considerations for Forest Health and Productivity:

- *Scope:* Forest managers can influence the magnitude of the climate-driven impacts of abiotic disturbances, pests, and pathogens. They can control forest composition, structure, and specific processes and infrastructure to reduce some risks. Some impacts, such as increasingly frequent pest outbreaks, may only be controlled by working regionally with other landowners and state or provincial governments. It is helpful to identify all forest health risks, monitor the threat level, and understand your ability to influence the impact of each forest health risk.
- *Uncertainty*: Climate change may slightly increase the frequency of extremely large storm events that have spatially unpredictable impact areas. A slightly more predictable increase in pests, pathogens, and invasive species is also likely, with range expansions that will have chronic impacts. Before planning for climate change, forest managers should first focus on reducing risk from threats that have a significant effect and are likely, impactful, near-term, and manageable (e.g., the impact of extreme rain events on soil erosion) over uncertain and/or far-future changes (e.g., more frequent hurricanes and tornados).
- *Near-term vs Long-term:* Near-term changes in disturbance due to climate change are more certain than long-term changes, though both are likely to be impactful over the rotation lengths typical of the Northeast. Both short-term and long-term strategies should be explored, despite the uncertainty around long-term projections. Long-term strategies should implement adaptive management techniques, creating or maintaining flexibility to alter course in response to changing circumstances such as new environmental impacts, market changes, and/or improved climate projections.
- *Planning Horizons:* Consider planning horizons for different types of operations. For example, the planning horizon will differ for road maintenance (0 to 5 years), harvest operations (5 to 20 years for thinning, selection harvests, and first shelterwood entries), and regeneration operations (40 to 80 years for final shelterwood entry, clear cuts, and planting). Road-maintenance plans should consider recent weather trends and current experiences, but road upgrades may also need to consider climate projections for the mid-century (2040–2060).
- *Landowner Context:* The planning should be designed to meet owner needs, reflect the financial resources available to reduce climate risks, and consider the level and certainty of climate risk to essential forest resources—especially wood production **(SFI Objectives 1 and 9).**
- *Ecosystem Benefits:* Using climate-smart forestry to address the abiotic, biotic, and human risks exacerbated by climate change may also benefit water resources, biological diversity, unique cultural and geological values, recreation, visual values, resources for which Indigenous Peoples have rights, and fire resilience **(SFI Objectives 2 through 6, 8, and 10).**

Climate-Smart Management Actions:

Favorably Ranked Actions:

- Use integrated pest management, which purposely accounts for changes in climate and weather. This includes tracking the results of state, provincial, and federal monitoring programs and potentially having field staff monitor or flag pest and pathogen outbreaks affected by changing climate and weather patterns.
- Have invasive species management policies to reduce the spread of climate-change-related invasive species. Such policies may include guidance on control, equipment hygiene, the use of native species seed-mixes, cleaning nursery stock, and minimizing the movement of non-processed wood.
- Apply practices that improve the health and ability of trees to resist climate-change-related pests and pathogens, as well as existing pests and pathogens.
- Manage vertebrate pest populations such as deer, which have increased due to climate change, when they damage desired species.
- Require low-impact logging practices to control residual tree (e.g., wounding) and soil damage (e.g., excessive rutting).
- Participate in and support pest prevention and control programs that use climate change information.
- Manage for future stand conditions and health (e.g., regen as future canopy tree plus future climate conditions).
- Manage use of harvest treatments at the landscape scale for a diversity of structure, patch size, age class, and forest types that are resilient to expected changes in disturbance regimes, such as wind, fire, insect pests, and pathogens. Allow tree species to widely regenerate and shift local ranges in response to changes in climate.

Other Actions:

- Reduce risks of damage due to climate-related pests and pathogens (e.g., balsam wooly adelgid, white pine needle damage) and existing pests by doing the following:
    - o Apply Integrated Pest Management and chemical control in areas heavily infested with pests.
    - o If a stand is damaged or is at high risk of damage from pests or pathogens, promote practices that increase the host's vigor or replace the host with well-adapted non-host tree species or genotypes during thinning and planting.
    - o Restrict harvesting and transporting logs in or near stands with known infestations.
- Alter forest structure to reduce fuel loads and ladder fuels. Alter forest composition to increase the proportion of deciduous species, and establish/improve fire breaks to lower the risk and spread of unacceptably severe fire in forests with high fire risk (e.g., red or pitch pine stands).
- Even if fire, pest, and pathogen risks are low, implement various management activities or silvicultural treatments

across areas with similar starting conditions to diversify stand and forest conditions and monitor different management approaches to evaluate improvements in forest resilience to future, unplanned climate changes.

- Actively promote broad social awareness and increase education about the anticipated effects of climate change on fire regimes.
- Share climate adaptation plans and examples of implementation with the public.

Resources:

Beaury, E.M., Fusco, E.J., Jackson, M.R., Laginhas, B.B., Morelli, T.L., Allen, J.M., Pasquarella, V.J. and Bradley, B.A., 2020. Incorporating climate change into invasive species management: insights from managers. Biological Invasions, 22, pp.233-252 *(provides good insights management of invasive species under climate change).*

Catanzaro, P., D'Amato, A.W. and Huff, E.S., 2016. Increasing Forest Resiliency for an Uncertain Future. University of Massachusetts, Cooperative Extension Landowner Outreach Pamphlet: Boston, MA, USA, p.32 *(provides stand-level guidance on climate smart forestry for managing forest health).*

Emilson, C., Bullas-Appleton, E., McPhee, D., Ryan, K., Stastny, M., Whitmore, M. and MacQuarrie, C.J., 2018. Hemlock woolly adelgid management plan for Canada. Natural Resources Canada / Ressources naturelles Canada. Canadian Forest Service, Great Lakes Forestry Centre, Sault Ste. Marie, Ontario. Information Report No.GLC-X-21 *(a useful guide to eastern hemlock and HWA management for Canadian provinces).*

Janowiak, M.K., D'Amato, A., Swanston, C.W., Iverson, L.R., Thompson, F.R., Dijak, W.D., Matthews, S., Peters, M.P., Prasad, A., Fraser, J.S. and Brandt, L.A., 2018. New England and northern New York forest ecosystem vulnerability assessment and synthesis: a report from the New England Climate Change Response Framework project *(No. NRS-173). USDA Forest Service, Northern Research Station (summarizes major climate risks for major forest types in northeast).*

2.3 PROTECTION AND MAINTENANCE OF WATER RESOURCES

Background:

One goal of sustainable forestry is to protect the water quality and quantity of rivers, streams, lakes, wetlands, and all water bodies. Forest ecosystems help regulate surface water and groundwater flows across landscapes. They also influence the interactions of soil, water, climate, topography, and biological activities that affect aquatic habitats and water quality.

Forest management activities can significantly alter forest soils and cover, affecting water flows, quality, and quantity, and related habitats. Appropriate forest management conserves soil and manages forest cover to minimize downstream impacts. Inappropriate management may result in soil compaction, erosion, loss of stream bank buffering capacity, increased stream sediment loads, degradation and destruction of riparian and aquatic habitats, and altered flow regimes. Stream flows can vary depending on tree cover in a catchment, which can be managed by harvesting and planting. Changes in tree cover can increase flooding risk or reduce water flow in streams and impact human safety and property. Forest ecosystems help regulate surface water and groundwater flows across landscapes. They also greatly influence the interactions of soil, water, climate, topography, and biological activities that affect aquatic habitats and water quality. Management activities can help protect water resources from climate change by addressing changes in precipitation that affect soil movement, riparian areas, and surface water flows.

Climate Change Impacts on Water Resources in Forested Landscapes:

Current and Future Water Resource Trends:

Projections about soil moisture and drought are less certain than temperature because summer precipitation and cloud cover projections are variable. Warming will likely result in less snow, earlier snowmelt, and more rain-on-snow events, reducing the length of the winter operational season. The number of soft ground days in spring and fall will continue to increase, reducing harvesting days and increasing the risk of soil erosion. Groundwater levels may peak earlier in the spring and have more extended lower base flow periods, especially in the summer. Additionally, projected temperature increases combined with most projections of less summer rain could result in greater rates of evaporation; as a result, average late-summer soil moisture levels are projected to decline, increasing drought frequency.

The frequency of short-term (one to three months) drought is projected to increase significantly under all scenarios and become more widespread under high-emissions scenarios. The frequency of medium-term (three to six months) and long-term drought (> six months) is projected to increase slightly. On rural, unregulated rivers in New England, where snowmelt dominates the annual hydrological cycle, there has been a trend of earlier snowmelt runoff, with most runoff occurring one to two weeks earlier over the last 30 years. Rain-on-snow events are increasing in frequency, mainly in the late winter but also at other times, and will become increasingly more frequent. The timing and number of low-flow events that typically happen toward the end of summer are good indicators of stream flow, water supply, and drought. These have remained mostly the same in the region in the past 100 years.

Planning for Climate Change

Recognizing that climate change is already changing weather and rainfall patterns, conformance with requirements described in **SFI Performance Measures 3.1 and 3.2** and their indicators are likely to contribute to climate-smart forestry for water resources, including **SFI Objective 9 Climate Change.**

Climate-Smart Considerations:

- *Scope:* The scope for managing water resources is essentially unchanged. Managers should remain focused on managing and planning stream crossings and water diversion structures. They should consider how the new normal of extreme rainfall affects road and water diversion management. Managers can also consider the management of watershed cover. Watersheds where more than 35% of the canopy has been removed may experience severe flow events, as canopy cover moderates rainfall and stream flow events.
- *Uncertainty:* It is challenging to predict extreme rainfall events, but stream crossings and water diversion structures (e.g., road drainage systems, skid road humps) can be planned to account for these extreme flow events.
- *Planning Horizon:* Road planning and management should consider the most recent climate projections for extreme weather and rainfall. The rate of climate change is unlikely to outpace road maintenance. Still, roads may need to be moved or significantly upgraded to account for projected increases in extreme rainfall events.
- *Landscape Context:* Climate change exacerbates water quality issues, which will be most significant along riverbanks and in hilly landscapes. Watershed canopy cover thresholds should also be considered.

Climate-Smart Management Actions:

Favorably Ranked Actions

- Use federal, state, or provincial water quality best management practices that have been updated to address climate change (**SFI Performance Measure 3.1, Indicator 1**).
- Systematically apply road management practices to reduce the impacts of extreme rainfall events and water drainage and avoid stream sedimentation (**SFI Performance Measure 3.1, Indicator 3**).
- Have programs that use climate and other information to update the identification of wet-weather tracts and definitions of acceptable operating conditions (**Performance Measure 3.1, Indicator 3; SFI Performance Measure 3.2, Indicator 3**).

Other Actions

[NONE: Additional actions were not identified in available scientific literature.]

Resources:

Maine Forest Service. 2017. Best Management Practices for Forestry: Protecting Maine's Water Quality, Third Edition. Maine Forest Service, Augusta, ME *(includes guidance on managing for water quality in conformance with Maine statues).*

New Brunswick Minister of Natural Resources. 2014. Forest Management Manual for New Brunswick Crown Lands: Results-Based Forestry Option. New Brunswick Minister of Natural Resources, Fredericton, NB *(includes guidance on managing for water quality in conformance with New Brunswick statues).*

New Brunswick Minister of Natural Resources. Watercourse and Wetland Alteration Technical Guidelines. New Brunswick Minister of Natural Resources, Fredericton, NB *(provides guidance on managing stream crossings and operations adjacent to wetlands).*

New Hampshire Division of Forests and Lands. 2016. Best Management Practices for Erosion Control on Harvesting Operations in NH. New Hampshire Division of Forests and Lands, Manchester, NH *(includes guidance on managing for water quality in conformance with New Hampshire statues).*

New York DEC: Division of Lands and Forests. 2018 New York State Forestry Bmp Field Guide: Voluntary Best Management Practices For Water Quality, 2018 Edition. Department of Environmental Conservation, Division of Lands and Forests, Albany, NY *(includes guidance on managing for water quality in conformance with New York statues).*

Vermont Department of Forests, Parks and Recreation. 2019. Vermont Water Quality: Acceptable Management Practices Manual for Logging Professionals. Vermont Agency of Natural Resources, Department of Forests, Parks and Recreation, Montpelier, VT *(includes guidance on managing water quality in conformance with Vermont statutes).*

2.4 CONSERVATION OF BIOLOGICAL DIVERSITY

Background:

Forests, particularly native forests, support a substantial proportion of the planet's biological diversity and terrestrial species. Biodiversity enables an ecosystem to recover from disturbance and maintain essential ecological processes to support forest productivity, wildlife, and ecosystems. Forest biodiversity includes forest plants and animals, aquatic species, threatened and endangered species, Forests with Exceptional Conservation Value, old-growth forests, ecologically important sites, diverse forest types, natural communities, and the condition of vegetation.

Habitat loss contributes to the decline of many species. Species requiring specific habitat characteristics – such as a particular plant community, a particular hydrologic or temperature regime, or a particular size of habitat patch – can be particularly vulnerable to habitat changes. Forest management activities can enhance, reduce, or maintain natural communities and habitats for diverse species. Increasing forest resilience to climate change impacts can improve biodiversity conservation.

Climate Change and Impact on Biodiversity

Climate change is already affecting the region's biodiversity. These impacts are projected to increase as this region will experience a more significant temperature change than other regions in North America. Increasingly, wildlife species are moving northward, including species from the Northeast. Changes in seasonal rainfall patterns exacerbate late summer drought and increase drought stress levels and frequency. Increasing temperatures are allowing wildlife parasites such as Winter Moose Tick (*Dermacentor albipictus*) and forest pests such as Hemlock Wooly Adelgid (*Adelges tsugae*) to become more prevalent, stressing native wildlife and degrading their habitats. Because each species will respond individually to these impacts, the composition of natural communities and wildlife habitats that we take for granted will change. While populations of some species and their habitats will increase, climate change could extirpate other species, especially northern and boreal species, and significantly alter natural communities and wildlife habitats.

Many different actions can be applied to reduce climate change risks to biodiversity. They can include applying "no-regrets" conventional conservation practices, which are already in place to help mitigate other ecosystem stresses and habitat fragmentation, restore natural habitats, and maintain species and functional diversity. They can also include novel conservation practices such as increasing habitat connectivity, protecting small-scale climate refugia where conditions can allow species to persist, and enhancing the recovery of natural ecosystems after extreme events.

Most conservation strategies can be fine-, meso-, or coarse-filter, each suitable for different scales. A multiscale approach to conservation can help hedge against uncertainty, flexibly applying new actions and information, and modifying actions to meet the needs of each landowner. These three strategies can be used but must be adapted to work in managed forests exposed to climate change. Many existing conservation strategies already contribute to the resiliency of biodiversity.

Fine-Filter
Fine-filter strategies focus on conserving individual rare species (Threatened and Endangered [T&E] or at-risk S1 or S2 species) and species vulnerable to climate change. National, provincial, and state species vulnerability reports can be used to determine whether any forest species are threatened by climate change (see **Resources** section below).

Two methods have been applied to identify key landscape features for conserving species in the future: *ecological niche modeling* and *climate resilience modeling. Niche modeling* focuses on identifying the future locations with suitable environmental conditions for species and can be described as conserving the "actor," i.e., species. This approach may work well for selecting areas critical to conserving species with long-distance dispersal abilities (e.g., birds, large mammals, and some reptiles). *Climate resilience modeling* focuses on identifying climate refugia locations that will change slowly, such as mountain tops facing north, and can be described as conserving the "stage." This approach may work well for selecting areas critical to conserving species with slow dispersal abilities (e.g., amphibians and small mammals). These approaches can be combined to identify regional coarse filter strategies for conserving key forest natural communities and T&E or at-risk species in the short-term.

Meso-Filter
Meso-filter conservation strategies focus on conserving specific ecosystem elements important to many species, especially non-charismatic, overlooked species such as harmless insects, fungi, and bryophytes. These elements include forest structures such as logs and snags, landscape structures such as pools, springs, streams, reefs, and hedgerows, and ecological processes such as fires and floods. These will continue to be important for conserving biodiversity and wildlife.

Coarse-Filter
Coarse-filter strategies seek to conserve either key sites as determined by natural elements unaffected by climate change or sites with low climate velocity that are expected to be refugia for climate-displaced species. With climate change, this includes *climate refugia, biodiversity stages,* and *landscape connectivity.*

Climate refugia are areas of landscapes that are partially resistant to the impacts of climate change because warming will be mitigated (e.g., deep ravines, north-facing slopes, streams with high levels of groundwater inflow), elevation gradients are broad, or natural forest communities are comprised of species resistant to climate change, at least in the short-term (e.g., northern hardwood forests in many areas in the north edge of this region).
Biodiversity stages are landscape areas with uncommon soils and topographic positions and tend to have high species diversity. While the species present at these sites may change with the climate, these sites will likely always have unusual and rare natural communities. State and provincial natural heritage programs can help identify biodiversity stages.

Landscape connectivity is the degree to which a landscape allows for wildlife movement. Landscapes with high connectivity will help species shift ranges and track their climate niche. Maintaining a network of riparian zones (areas associated with riverbanks) can contribute to landscape connectivity if the network is continuous and wide enough in some places to accommodate species habitat needs.

Climate-Smart Considerations

- *Scope:* The spatial scope of managing biological diversity with or without considering climate change is unchanged. Coarse-filter approaches remain important, especially the connectivity and conservation of unique areas. Climate change adds a time dimension, making species changes hard to predict. Meso-scale conservation primarily focuses on unique and biologically important features such as forest structure. Fine-filter strategies should consider range changes for species and natural communities and the disassembly of rare natural communities into new ones.
- *Uncertainty:* Two things are uncertain: the timing and speed of species range changes. We do not know how long the current distribution of forest types (habitats) will remain the same. A slight decline of northern conifer species is projected by mid-century, with more significant declines and species shifts by the

end of the century, especially in the region's southern edge. Tree and bird species already show evidence of range shifts as they track their climatic niches. It is uncertain whether all species can effectively track these. We don't know whether the populations and ranges of these species will rapidly decline or be maintained at the northern edge of their contemporary ranges. The widespread decline of many species has been globally projected. This suggests that the number of T&E and at-risk species may significantly increase and challenge landowners to keep up with regulatory or certification requirements regarding these species.

- *Planning Horizon:* Landscape configuration, especially for connectivity, requires long-term (30–100 years) planning to avoid interrupting management plans to meet landowner objectives. Land managers can consider a flexible shifting mosaic model to maintain connectivity across landscapes for generalist forest species and perhaps maintain a fixed, core connectivity network for late-successional species. Planning should consider how to align best short-term (10–20 years) spatially explicit objectives with long-term projected climate changes to habitat at the landscape level to ensure long-term continuity of connectivity.
- *Landscape Context:* Managers should consider the conservation of climate refugia (including stream areas), biodiversity stages, and connectivity across landscapes.
- *Ecosystem Benefits:* When well-coordinated, forest biodiversity and climate change management can also improve forest carbon (e.g., improved forest management that increases snag density and/or deadwood) and water resources (e.g., a connectivity network framed on conserved riparian zones).

Climate-Smart Management Actions

Favorably Ranked Actions

- Identify and conserve sites that provide refuge to at-risk species with enduring meso-climates. This may include protected canyons and ravines, northern slopes, and areas near cold-water bodies.
- Maintain a network of habitat corridors (e.g., a buffer network along stream riverbanks) to support species range shifts in response to climate change.
- Participate in local conservation planning efforts so that your company's land base can maintain or increase its network of habitat corridors to support regional species range shifts in response to climate change.
- Identify and manage climate risks (e.g., fire, drought, extreme precipitation events, ecosystem changes) for Forests with Exceptional Conservation Value, old-growth forests, and ecologically significant sites to the extent that it is practical.
- Participate in state, provincial, or regional conservation planning for biological diversity (e.g., state forest or wildlife action plans, wildlife recovery plans) that significantly incorporate climate change information and use results in forest management planning.

Other Actions

- Mitigate other threats to forest ecosystems, such as invasive species, insect pests, and forest fragmentation.
- Manage for flexibility using a portfolio of forest management approaches for maintaining forest ecosystems experiencing climate change.
- Increase investment in climate-related science and research about managed forest ecosystems.
- Increase communication of knowledge about climate change impacts on managed forest ecosystems to policymakers and stakeholders.
- Provide educational opportunities and summaries of primary literature for forest management staff to learn and network about climate change and its impacts on managed forest ecosystems.

Resources

Anderson, M. G., M. Clark, and A. Olivero Sheldon. 2012. Resilient sites for terrestrial conservation in the Northeast and Mid-Atlantic region. The Nature Conservancy, Eastern Conservation Science, Eastern Regional Office, Boston, Massachusetts *(identifies areas with potential high climate resilience in the northeast).*

Anderson, M. G., M. Clark, and B. H. McRae. 2015. Permeable landscapes for climate change. The Nature Conservancy, Eastern Conservation Science, Eastern Regional Office, Boston, Massachusetts *(identifies high-value dispersal networks areas with high climate resilience in the northeast).*

Assisted Migration Work Group. 2017. Guidelines for Implementing Assisted Migration of Plants on Agency Lands. Agency of Natural Resources, Montpelier, Vermont *(provides a framework for guidance and evaluating environmental considerations of assisted migration of tree species).*

Bennett, Karen P. editor. 2010. Good Forestry in the Granite State: Recommended Voluntary Forest Management Practices for New Hampshire (second edition). University of New Hampshire Cooperative Extension, Durham, N.H *(through guidance and description of on-the-ground practices for conserving biodiversity and wildlife that can be used with general climate change guidance for New Hampshire).*

Heller, N. E., and E. S. Zavaleta. 2009. Biodiversity management in the face of climate change: a review of 22 years of recommendations. Biological Conservation 142:14–32 *(identifies numerous biodiversity adaptation strategies).*

Janowiak, M.K., D'Amato, A., Swanston, C.W., Iverson, L.R., Thompson, F.R., Dijak, W.D., Matthews, S., Peters, M.P., Prasad, A., Fraser, J.S. and Brandt, L.A., 2018. New England and northern New York forest ecosystem vulnerability assessment and synthesis: a report from the New England Climate Change Response Framework project (No. NRS-173). Northern Research Station *(synthesizes vulnerability of forest natural communities in the Northeast).*

Lombard, K., M.G. Anderson, K. Barlow, G. Goodwin, K. Serbesoff-King, N. Sferra, J. Wraithwall (editors). 2021. Managing for Climate Resilience on The Nature Conservancy Preserves and Managed Lands in the eastern United States. The Nature Conservancy, Center for Resilient Conservation Science *(describes landscape-scale biological conservation practices).*

Neily, P. and G. Parsons. 2017. A Field Guide to Forest Biodiversity Stewardship. Forestry Division and Wildlife Division, Renewable Resources Branch, Nova Scotia Department of Natural Resources.

New Hampshire Fish & Game Department. 2013. Ecosystems and wildlife climate change adaptation plan. New Hampshire Fish and Game Department, Concord, NH *(identifies at-risk natural communities and species vulnerable to climate change in NH).*

Ontario Ministry of Natural Resources. Forest Management Branch. 2010. Forest Management Guide for Conserving Biodiversity at the Stand and Site Scales. Toronto: Queen's Printer for Ontario. 211 pp. *(describes regional stand-level and landscape-level biological conservation practices).*

Palik, B.J., D'Amato, A.W., Franklin, J.F. and Johnson, K.N., 2020. Ecological silviculture: Foundations and applications. Waveland Press *(describes basic ecological forestry practices that benefit wildlife and biodiversity at the stand- and landscape level).*

Schlesinger, M. D., J. D. Corser, K. A. Perkins, and E. L. White. 2011. Vulnerability of at-risk species to climate change in New York. New York Natural Heritage Program, Albany, NY *(identifies at-risk natural communities and species vulnerable to climate change in NY).*

Whitman, A., A. Cutko, P. De Maynadier, S. Walker, B. Vickery, S. Stockwell, and R. Houston. 2013. Climate change and biodiversity in Maine: vulnerability of habitats and priority species. Report SEI-2013-03. Manomet Center for Conservation Sciences (in collaboration with Maine Beginning with Habitat Climate Change Working Group), Brunswick, ME *(identifies at-risk natural communities and species vulnerable to climate change in ME).*

2.5 MANAGEMENT OF VISUAL QUALITY AND RECREATIONAL BENEFITS

Background:

The lifestyles and economies of many rural communities in the region rely on nature-based recreation and tourism. Forests have long been used for recreation and other leisure activities. The location and accessibility of forests and the availability of recreation facilities can be critical to forest-based recreation and tourism. Forest landowners can support nature-based recreation by managing access and the visual impacts of forestry operations where it is consistent with their forest management objectives **(SFI Objective 5).**

Climate Change Impacts on Visual Quality

Climate change may change landscape-level management and its visual impacts. Direct climate change impacts such as more frequent disturbances may require very large clear-cuts or areas of unsightly salvage logging. Indirect climate impacts on viewsheds can include renewable energy siting, increasing intensification of forest management, expanded long-rotation forestry (which reduces roadside scenic views), and wider roads to improve the natural light on road surfaces. Landowners can mitigate hard-to-control climate-related visual impacts through stakeholder communication and consider how extreme disturbance impacts due to climate change might have visual effects **(SFI Performance Measure 5.1).**

Climate change may tangibly reduce recreational access provided on private lands. Extreme rainfall events may wash out logging roads, limiting recreational access and trails. They may also necessitate closing logging roads to recreational users for extended periods because of washouts or to prevent rutting and other damage to road surfaces **(SFI Performance Measure 5.4).**

Climate Change Impacts on Recreational Benefits

Climate change may change recreational pressure and behavior on private forest lands with recreational access. For example, hotter summers may lead to greater use of water destinations. The number of recreationists and the length of the summer season is increasing, which may increase demands for recreation and its need for management. Recreationist encounters with operations, including logging trucks, may increase, especially if weather patterns further reduce the percentage of days that roads are operable.

An increase in average winter temperature reduces snowfall and snowmobiling recreation in some years. Regional records and modeling indicate that snow recreation days have declined by 15%, and the number of winter bare-ground days is now more significant than the number of snow recreation days. In some areas, snowmobilers are switching to using tracked ATVs, which may increase impacts on motorized trails. Landowners may have to consider new policies for managing recreational access and work with recreation groups to support recreation and minimize both its impacts and conflicts with users on their lands **(SFI Performance Measure 5.4).**

Climate-Smart Considerations

- *Scope:* The scope for managing recreational benefits is largely unchanged. The areas of most significant concern will be managing road access for recreation and managing trail stream crossings and water diversion structures. The new normal of extreme rainfall events continues to impact trails and associated water diversion strictures. It may be necessary to close or gate more access roads during certain seasons to prevent road damage or water quality issues caused by recreational activities. This is particularly important during spring and fall when soil moisture content is high, leaves are not on trees absorbing rain, the ground is not frozen, and roads are more vulnerable to damage. Although there may be opposition to a restrictive approach, it may be crucial for protecting the environment

and ensuring the long-term sustainability of our recreational resources.
- *Uncertainty:* An increase in extreme rainfall events makes it necessary to plan for variable flow and potential water quality impacts using stream crossings and water diversion structures on trails. Decade-scale changes in recreational trends, such as the increasing use of trails for ATVs or foot traffic during winter, add a layer of complexity to recreation management under climate change.
- *Planning Horizon:* Recreational partners should consider the most recent climate projections for extreme weather and rainfall when planning trails and stream crossings. Given the decline in volunteers for recreation trail groups, the rate of climate change might very well outpace trail maintenance. Trails near streams may need to be moved or significantly upgraded to account for projected increases in extreme rainfall events. Managers should avoid over-planning or over-committing into the future, as recreational trends can shift on the decade scale in part in response to climate change.
- *Landscape Context:* Climate change impacts exacerbating recreational trail issues will be greatest in riparian zones and hilly landscapes.

Climate-Smart Management Actions

Favorably Ranked Actions

[NONE: Managers did not identify or recommend any actions that were practical and/or in use.]

Other Actions

- Have a program to address visual quality management that incorporates aesthetic considerations in harvesting, road maintenance, landing design/management, and other management activities **(SFI Performance Measure 5.1).**
- Work with recreational groups to manage existing recreational opportunities and apply recreation management practices that consider climate change impacts (e.g., road and trail washouts), and/or add new opportunities, where consistent with forest management objectives (supports **SFI Performance Measure 5.4**).
- Identify and manage changes in recreational pressure due to climate change by working with recreational user organizations and tracking internal or external user trend data (supports **SFI Performance Measure 5.4**).

Resources

Ontario Ministry of Natural Resources. Forest Management Branch. 2001. Management Guidelines for Forestry and Resource-based Tourism. Queen's Printer for Ontario *(general guide to actions and practices that can be used to reduce visual and aesthetic impacts for tourism, some of which might be climate-smart, depending on context).*

O'Toole, D. et al. 2019. Climate change adaptation strategies and approaches for outdoor recreation. Sustainability, 11(24), p.7030 *(includes a list of practices, some of which can be used to manage recreation in managed forests in a changing climate).*

2. 6 PROTECTION OF SPECIAL SITES

Background:

Special Sites are cultural sites and unique geological features such as remarkable waterfalls or cliffs that require careful management to conserve their history and culture. Most managers are often already aware of Special Sites and make efforts to conserve them. Culturally important sites are documented areas such as cemeteries, Native American sacred sites, and archeological sites. Cultural sites hold a significant place in cultural history and play a key role in community cohesion and sense of place. Many sites may have features that make them resilient to climate change (e.g., unique waterfalls), so only some sites and their access may be vulnerable to climate change.

Climate Change Impacts on Special Sites

Forest managers can assess special sites' vulnerability to climate change and then consider whether to apply actions that reduce that vulnerability, or at least preserve cultural and historical significance for sites that cannot be maintained. For example, the increased frequency of extreme rainfall events linked to climate change may accelerate natural and uncontrollable riverbank erosion or scour historical sites along rivers. While it may be untenable to maintain the site, it may be possible to encourage state and local historical societies to preserve the identity of the site through the recording of interviews, the conservation of relevant reports and related materials, and local history signage (e.g., Canada Road in western Maine).

Climate change may not affect most unusual geological features in forested landscapes, with some exceptions, such as ice caves. Ice caves can be culturally significant, a habitat for rare insect and bat species, and retain ice year-round, and they may be at risk from warming temperatures. Managing a closed forest canopy may provide some protection by helping retain snow and minimizing the delivery of warm rainwater during the winter. Climate-related extreme rainfall events may sometimes damage logging roads and reduce access to important cemeteries and archeological sites.

Climate-Smart Considerations

- *Uncertainty:* The impact and timing of extreme events, especially rainfall events, will make identifying and conserving low-lying cultural sites difficult.
- *Planning Horizon:* The significance and importance of history and culture, plus the climate change projections, suggest planning through the next two decades and, when practical, to the end of the century.
- *Landscape Context:* Areas most vulnerable to climate change are those adjacent to streams and rivers, and their conservation should be prioritized.

Climate-Smart Management Actions
Favorably Ranked Actions
[NONE: Managers did not identify or recommend any actions that were practical and/or in use.]

Other Actions
- Identify and manage climate risks (e.g., fire, drought, extreme precipitation events, and ecosystem changes) that are impactful for each Special Site, considering their unique cultural qualities to the extent that it is practical.

Resources
Carmichael, B., et al. 2018. Local and Indigenous management of climate change risks to archaeological sites. Mitigation and Adaptation Strategies for Global Change, 23, pp.231-255 *(short description of the process for identifying cultural site risk).*

Ontario Ministry of Natural Resources. Forest Management Branch. 2007. Forest Management Guide for Conserving Cultural Heritage Values. Toronto: Queen's Printer for Ontario. 211 pp. *(general guide to actions and practices that can be used to manage special sites, some of which might be climate smart depending on context).*

Yu, P., et al. 2022. Chapter 4: A review of vulnerability assessments for cultural resources of the NPS. Pages 94-132 in Peek, K.M., B. R. Tormey, H.L. et al. (editors). 2022. Climate change vulnerability assessments in the National Park Service: An integrated review for infrastructure, natural resources, and cultural resources. Natural Resource Report NPS/NRSS/CCRP/NRR—2022/2404. National Park Service, Fort Collins, Colorado. https://doi.org/10.36967/nrr-2293650 *(a detailed description of methods for identifying cultural site risk).*

2.7 EFFICIENT USE OF FIBER RESOURCES

Background:
The efficient use of fiber resources focuses on minimizing waste and ensuring that fiber resources are processed, sorted, trucked, and delivered for best use. Central to this objective is increasing fiber utilization through logger training or incentives to encourage efficient use, the exploration of new markets to increase utilization of underutilized species and low-grade wood, and/or product separation inspections and evaluations. Efficient use of fiber resources can also be achieved by having a program for managing harvest residues (e.g., slash, limbs, tops) considering economic, social, and environmental factors to maintain soil quality and manage the build-up of fuel on the forest floor.

Climate Change and Fiber Efficiency
Opportunities driven by market responses to climate change issues and climate change impacts are affecting the efficient use of fiber resources. Supply chains are increasingly focusing on reducing the greenhouse gas (GHG) emissions of forest products, including product GHG intensity (CO2e tons/unit of product). Hence, the efficient use of wood fiber can be defined as maximizing wood product value and reducing product GHG intensity. Specific markets are developing in response to climate change and GHG emission issues, such as those purchasing wood such as mass timber that can only be supplied by extended rotations, which grow larger trees at lower GHG intensities than short-rotation forests. Finally, climate change has increased the frequency of extreme weather events. These events are increasingly disrupting forest operations and logging road networks.

Planning for Climate Change
A climate-smart response can address fiber marketing opportunities and the operational issues climate change poses. Markets can apply pressure to reduce product GHG intensity or increase GHG efficiency. As a result, a key strategy is to reduce GHG emissions from timber harvesting. This can include increasing equipment fuel efficiency and piece productivity by matching equipment to stand conditions (e.g., stocking levels and tree size). Careful monitoring of fuel use and GHG emissions can help improve product GHG intensity. Many loggers already use computer tablets to help improve harvest layout and equipment decisions that reduce travel time and fuel use. Avoiding unproductive or wet areas can increase harvest efficiency and minimize lost time, thereby reducing GHG emissions. Encouraging contractors to use fleet software to coordinate machinery can minimize transportation GHG emissions, thus decreasing the GHG emissions associated with harvested wood.

Because GHG intensity from harvested wood products (HWP) can be lower when harvesting larger diameter trees, stands managed for these markets may result in harvesting systems with lower GHG intensity than conventionally managed stands. Additionally, mass timber products can have lower embedded GHG emissions than concrete or steel, which further reduces the relative GHG intensity of buildings.

Emerging technologies can now estimate GHG intensity based on fuel use and wood harvesting or processing time, making it possible to measure the efficiency of harvesting, processing, and trucking raw wood resources in terms of GHG intensity. Future technological upgrades in harvest and process equipment will allow operators to track GHG emissions, associate them with different activities, and calculate GHG intensity for harvested wood.

The raw wood sorting process improves efficient fiber use, lowering the GHG intensity of products. Many landowners already invest in onsite wood sorting by using remote sorting yards to ensure that wood is sorted and processed by the highest grade possible. This allows the wood to be efficiently processed into long-lived products and leverages the mitigation benefits of carbon storage in HWP.

Finally, the increased frequency of extreme weather due to climate change increasingly disrupts forest operations and logging road networks. Equipment may be more frequently moved to find operable sites. Even though wood may be processed and sorted efficiently, disruptions can increase fuel consumption, GHG emissions, and HWP GHG intensity. Creative use of equipment, brush mats, skidder bridges, and culvert upgrades all contribute to overcoming the obstacles posed by climate change and extreme rainfall and help maintain efficient harvest operations. Open-ended operational plans can include contingencies for directing operators to alternative sites when medium-term weather forecasts indicate poor weather and soil conditions for selected sites.

Extreme weather may also increase the need for salvage operations, making it challenging to use fiber resources efficiently. Careful stand management can help avoid losses and salvage due to weather. Operator training can improve salvage volumes, processing rates, and merchandising of harvested wood.

Climate-Smart Considerations

- *Uncertainty:* The inability to predict the impacts of extreme weather events on resource access and standing timber will be a challenge. For access, roads can be built to reduce the effects of extreme rainfall, including culvert and stream crossing replacements suited for larger storms. Technological fixes (e.g., skidder bridges, slash mats) and operational planning may allow timber harvesting when poor weather impacts soil and limits harvest operations.
- *Planning Horizon:* Road access can be integrated with short-term and long-term road planning, over years and decades. Operational planning can create contingency plans for operations that are weeks and months away. Current climate impacts on access are expected to become worse as winter access declines with warming. Increasing the efficiency of wood harvesting, processing, and trucking requires managers to consider incentives and operator training as equipment across logging companies upgrades, likely every couple of years. Current efforts to improve sorting and fiber utilization toward longest-lived products will fluctuate with markets and mill availability.

Climate-Smart Management Actions

Favorably Ranked Actions

- Have a program or monitoring system to track the efficiency of fiber utilization and reduce product GHG intensity (CO2e/unit of wood product)
- Provide training or incentives to encourage professional logging contractors to reduce fuel use intensity (e.g., gallons/unit of wood).
- Provide training or incentives to encourage professional logging contractors to improve wood merchantability and grading into longer-lived products during harvest and processing.
- Explore markets for increasing merchantability and grading underutilized species and low-grade wood into longer-lived products.

Other Actions

- Apply or foster practices that use harvest residues to reduce GHG emissions. This could include retention to contribute to dead carbon pools, removal to avoid GHG emissions from catastrophic fires, and/or utilization for longer-lived products or heating.

Resources

Post-secondary operator programs: Canadian Woodlands Forum (New Brunswick, "Entry-level' Forestry Equipment Operator Training Program), Fleming College (Quebec), New Brunswick Community College (Mechanized Forest Equipment Operator program), Northern Maine Community College (Mechanized Logging Operations Program),Paul Smith's College (School of Logging), University of New Hampshire (Professional Logger Program) *(certificate programs aimed training entry-level or less experienced equipment operators on professional, safe, and efficient use of harvesting equipment).*

Other professional training programs: Training provided by the Northeast Master Logger Certification (NEMLC), Certified Logging Professional Program (CLP), Northeast Woodland Training, Inc., state forestry water quality BMP programs, and other equipment operator programs *(day or multiday training programs aimed current equipment operators).*

Consult dealer information and equipment training.

2.8 RECOGNIZE AND RESPECT FOR INDIGENOUS PEOPLES' RIGHTS

Background:

Recognition and respect for Indigenous Peoples' rights and Traditional Ecological Knowledge (TEK) are essential for sharing ecosystem benefits from sustainably managed forests. Indigenous Peoples often use TEK to sustainably manage the environment and to maintain cultural and spiritual connections with plants, animals, and ecosystems, which can be integral to their identity, language, beliefs, and well-being. Another component of recognition and respect for Indigenous Peoples is protecting spiritually, historically, or culturally significant sites.

Managers can work with Indigenous Peoples to integrate TEK in the management of forests and culturally significant natural resources in the face of climate change. Some Wabanaki Nations have culturally used over 130 species of plants and fungi for food, medicine, spiritual purposes, and livelihoods. Culturally important species include (but are not limited to) fish species such as alewives, blueback herring, American shad, American eel, and Atlantic salmon; game species such as moose, black bear, white-tailed deer, waterfowl, ruff grouse, turkey, snowshoe hare, and other small game; various furbearers; and plants such as medicinal plants, wild berries, wild grapes, sweetgrass, calamus root, paper birch, black ash, and fiddleheads.

Engaging with Indigenous Peoples on forest management and climate change adaptation increases cultural awareness. Forest managers can build relationships with local Indigenous Peoples by inviting the review of management plans and seeking guidance on integrating TEK when possible. This can improve climate change adaptive outcomes that can protect spiritually, historically, or culturally significant sites, plants, and animals, and improve the sustainable gathering of culturally important non-timber forest products on private lands.

Climate Change Impacts on Indigenous Peoples' Rights, Cultural Resources and Sites, and Traditional Ecological Knowledge

Climate change impacts on forests directly affect culturally significant species and ecosystems and likely affect TEK and tribal culture, activities, and economy. The distribution of culturally significant plant and animal species may shift northward, contract, or expand while their populations increase or decline. The timing of seasonal activities such as harvesting migratory fish runs and berry picking are shifting and may become more irregular, which strains the social and cultural sovereignty of Indigenous Peoples.

Black ash is a keystone cultural resource for the Wabanaki People, which is at risk of being widely eliminated by emerald ash borer (EAB). It faces an immediate risk of local destruction in the southern area of its range. Its use is a key tradition that has helped maintain cultural resilience in the face of past and present change. Some Tribal nations are conducting silvicultural experiments to maintain black ash populations. Others are experimenting with injecting selected black ash trees with the systemic insecticide emamectin benzoate to retain black ash seed sources and conserve genetic diversity.

Forest managers can assess the vulnerability of Indigenous Peoples' spiritually, historically, or culturally significant sites to climate change and then consider whether to reduce that vulnerability or at least to maintain cultural and historical significance for sites that cannot be protected from climate change. For example, the increased frequency of extreme rainfall events linked to climate change may accelerate natural and uncontrollable riverbank erosion or scour Indigenous Peoples' archeological sites or rock art along rivers. By consulting with local Tribal nations, forest managers may also learn whether preserving these sites or their cultural history and memory of the site might achieve positive outcomes. In some cases, climate-related extreme rainfall events may damage logging roads and reduce access to important Indigenous spiritual and cultural sites.

Climate-Smart Management Actions

Favorably Ranked Actions

[NONE: Managers did not identify or recommend any actions that were practical and/or in use.]

Other Actions

- When applicable, identify and manage climate risks (e.g., fire, drought, extreme precipitation events, ecosystem changes) for cultural resources on your land that Indigenous Peoples have rights to and which may be affected.
- Share information with Indigenous Peoples about climate risks that may affect cultural resources on your land.
- When appropriate, consult with Indigenous Peoples about TEK and its application to conserving and managing cultural resources affected by climate change.

Resources

Ontario Ministry of Natural Resources. Forest Management Branch. 2007. Forest Management Guide for Conserving Cultural Heritage Values. Toronto: Queen's Printer for Ontario. 211 pp. *(general guide to actions and practices that can be used to manage special sites, some of which might be climate smart depending on context).*

Pearson, J., Jackson, G. and McNamara, K.E., 2021. Climate-driven losses to Indigenous and local knowledge and cultural heritage. The Anthropocene Review, p.20530196211005482 *(provides background information for understanding climate impacts on TEK).*

Robitaille, P.A., Shahi, C., Smith, M.A. and Luckai, N., 2017. Growing together: A principle-based approach to building collaborative Indigenous partnerships in Canada's forest sector. The Forestry Chronicle, 93(1), pp.44-57 *(describes five principles, with 23 supporting strategies that can be adopted to facilitate collaboration between commercial landowners and Indigenous peoples, suited for Canadian forest managers, informational for U.S. forest managers).*

Wyatt, S., Fortier, J.F., Natcher, D.C., Smith, M.A.P. and Hébert, M., 2013. Collaboration between Aboriginal peoples and the Canadian forest sector: A typology of arrangements for establishing control and determining benefits of forestlands. Journal of Environmental Management, 115, pp.21-31 *(describes a flexible framework that ranges in landowner commitment and identifies different arrangements for engaging indigenous peoples' groups).*

2.9 CLIMATE-SMART FORESTRY

2.9.1 Climate Change Adaptation

Background:

Forest owners can address climate change by managing forests with climate adaptation and mitigation actions to increase their resilience and maintain their carbon capture potential. Climate change is creating long-term uncertainty for forest landowners. Unusual variations in weather patterns and an increased incidence of tree diseases and pests may adversely impact forest operations and managed forests by increasing tree mortality or diminishing forest productivity. It may also create more favorable growing conditions and increase forest productivity. Hence, forest landowners can benefit from identifying climate change impacts on productivity and ecosystems, opportunities for mitigation, and forestry management strategies that can optimize productivity.

Climate Change and Adaptation

Climate change may create long-term uncertainty for forestry managers. Variations in precipitation and temperature patterns, more frequent extreme weather events, and an increase of tree disease and pest outbreaks could negatively impact forest ecosystems and productivity by reducing tree health and vigor and increasing tree mortality. On the other hand, climate change could also facilitate greater forest productivity as atmospheric CO_2 levels increase, the growing season increases, temperatures moderate at high latitudes, precipitation increases, and the geographic ranges for some species expand. Forest landowners can use the best available science to identify and address the climate change risks to forests and forest operations and develop appropriate adaptation objectives and strategies that optimize their forestlands' productivity.

Adaptation planning typically follows a climate change risk assessment, which assesses the materiality, or significance, of each climate change risk based on its likelihood and local severity. Risks vary among regions, landowner objectives, and forest types and ages. The risks can include environmental, social, and economic risks influenced by climate change impacts that affect a management unit or its forest stakeholders (e.g., **SFI Objectives 1 to 8 and 10**, Sections 2 through 8 and 10 of this handbook). A risk assessment uses the best available scientific and economic information to evaluate the probabilities and consequences of climate change. The forest management adaptation plan addresses the discovered material climate change risks.

A materiality evaluation of climate change risks should consider the size, timing, and likelihood of their impact on the management company, forest, and key stakeholders. Climate change risks are already being experienced and impacting forest sector assets. Management companies should consider their ability to mitigate or control a specific climate change risk. A materiality and mitigation assessment can provide insight into whether existing management plans address critical climate change risks and the practical ways to upgrade existing management plans. Examples of standardized climate change risk assessment methods can be found in the Resources section.

A climate change adaptation plan addresses material risks and opportunities to increase the forest ecosystem's resilience. Adaptation plans should consider alignment with local, state, and regional adaptation plans to contribute to the overall alignment of regional adaptation efforts. Adaptation strategies may include adjusting to account for impacts such as extreme rainfall events on road networks, shorter winters on harvest planning, and opportunities such as using the selection of new tree source locations to improve long-term growth and yield. Climate change may affect growth rates by affecting productivity through long-term drought or changes in forest health. Hence, forest management adaptation plans may include an update of forest inventory and revised planned harvests when growth rates increase or decline.

Climate-Smart Considerations

- *Scope:* Adaptation planning focuses on forest management units and landowner objectives. It should consider many potential impacts on the company and relevant stakeholders.
- *Uncertainty:* The materiality of many climate change risks becomes more uncertain with increasing planning horizons, given that the timing and impact of different climate change risks vary with time.
- *Planning Horizon:* Risk assessment and adaptation planning should match the time horizon and specificity of other management planning efforts, such as road building and maintenance plans and annual, 5-year, 10-year, and 20-year harvest plans.
- *Landscape Context:* Southern regions of the area are expected to face forest health, pest and invasive plant species, and tree species resiliency issues before the northern regions for most tree species.

Climate-Smart Management Actions

Favorably Ranked Actions

- Identify regional- and/or stand-level climate impacts, vulnerabilities, opportunities, and risks and prioritize the response based on the likelihood, nature, and severity of the expected impact (**SFI Performance Measure 9.1, Indicator 1**).
- Identify practical strategies in plans for reducing the threat of climate-related risks to forests and extreme weather on road networks (**SFI Objective 1. Forest Management Planning, Performance Measure 1.1; SFI Performance Measure 9.1, Indicator 2**).
- Develop climate change adaptation strategies that account for the benefits of approaches that focus on resistance (maintain current forests), resilience (recover forests to former conditions), or facilitated transition (manage for future forests) (**SFI Objective 1. Forest Management Planning, Performance Measure 1.1**).
- Develop an adaptation plan to address priority climate change risks, which include periodic updates of forest inventory and recalculations of planned harvests when climate and related factors affect productivity; consideration of growth and yield models with climate data integration; documented harvest trends at sustainable levels; and the appropriate consideration and use of improved planting stock (**SFI Performance Measure 9.1, Indicator 2**).
- Report, plan to report annually, your progress toward achieving climate change adaptation strategies and plans to SFI. (**SFI Performance Measure 9.1, Indicator 4**).

Other Actions

- Document how company adaptation plan objectives and strategies fit within existing regional climate adaptation

strategies and plans, such as state wildlife and forestry action plans or state and provincial climate change plans (**SFI Performance Measure 9.1, Indicator 3**).
- Have acquired standing timber insurance.

Resources

See Appendix B for list of forest carbon models and adaptation resources

Janowiak, M., K. Schmitt, D. Shannon, P. Leopold, L. Brandt, S. Handler, T. Ontl, C. Peterson, C. Swanston. 2022. A Quick Guide to Adaptation Planning for Natural Resource Professionals. Northern Institute of Applied Climate Science, and USDA Northern Forests Climate Hub *(a quick guide to understanding the basics of climate adaptation planning).*

Todd A Ontl and others, Forest Management for Carbon Sequestration and Climate Adaptation, Journal of Forestry, Volume 118, Issue 1, January 2020, Pages 86–101, https://doi.org/10.1093/jofore/fvz062 *(academic but practical lists of adaptation and mitigation strategies/actions).*

SFI. 2022. Guidance to SFI 2022 Standards and Rules, Section 7. SFI, Arlington. VA *(guidance on climate-smart forestry adaptation, especially risk assessment, materiality assessment, and regional planning activities).*

Swanston, C. W.; Janowiak, Maria K.; Brandt, Leslie A.; Butler, Patricia R.; Handler, Stephen D.; Shannon, P. Danielle; Derby Lewis, Abigail; Hall, Kimberly; Fahey, Robert T.; Scott, Lydia; Kerber, Angela; Miesbauer, Jason W.; Darling, Lindsay; Parker, Linda; St. Pierre, Matt. 2016. Forest Adaptation Resources: climate change tools and approaches for land managers, 2nd ed. Gen. Tech. Rep. NRS-GTR-87-2. Newtown Square, PA: USDA, Forest Service, Northern Research Station. 161 p. http://dx.doi. org/10.2737/NRS-GTR-87-2 *(a toolbox of climate change tools for land managers).*

2.9.2 Climate Change Mitigation

Background:

Maintaining an array of ecosystem benefits beyond wood fiber production, where appropriate, is a long-held tenet of sustainable forestry. Forest managers have long considered management impacts on recreation, water quality, and wildlife. Climate change, new certification requirements (**SFI Objective 9 Climate-Smart Forestry**), pressure from supply chains and markets on climate change issues, and revenue opportunities from forest carbon offsets are leading forest managers to consider climate regulation – that is, greenhouse gas (GHG) emissions and mitigation – as another ecosystem benefit to consider for management.

Specifically, many forest managers are considering ways to maintain forests' GHG mitigation potential and mitigate forest GHG emissions where appropriate. This can include identifying and addressing opportunities to mitigate forest impacts to GHG emissions, including when managing effects on forest health (**SFI Objective 2, Forest Health and Productivity**), fire risk (**SFI Objective 10, Fire Resilience and Awareness**), other ecosystem benefits such as biodiversity (e.g., **SFI Objective 4, Conservation of Biological Diversity** when applying retention practices) and water resources (**SFI Objective 3, Protection and Maintenance of Water Resources** when protecting soils and using SMZs), increasing utilization efficiency (**SFI Objectives 7, Fiber Utilization Efficiency** when reducing waste or increase wood fiber utilization), and other actions to enhance the climate benefits associated with forest management. A crucial part of climate mitigation for forests is enhancing forest ecosystem resilience by ensuring adequate regeneration (natural or planted) on harvested sites, protecting existing or planned regeneration, and retaining vigorous trees during partial harvests. This requires a planned effort to identify and address GHG within the boundaries of forest management operations and the ability to report mitigation activities.

Climate Change and Mitigation

Forestry GHG assessments may be used to evaluate forest carbon offsets as an alternative revenue stream. They can also help address climate change and sustainability concerns from investors, landowners, and supply chains. Increasingly, climate change issues are becoming a factor for landowners and supply chains to maintain social license. Publicly-owned companies increasingly face shareholder pressure, which can cascade down supply chains. By developing organizational GHG assessments, companies may be able to meet reporting regulations before they become legally required. Mitigation activities may also help with employee retention, as younger employees increasingly care about the climate and make job decisions based on the employer's response to issues like climate change.

The first step in managing the carbon mitigation potential of a forest and evaluating offset opportunities is to use available forest inventory and harvest data and growth and yield models to estimate carbon storage and carbon fluxes. Avoiding forest conversion also helps maintain the mitigation potential of forests.

Forestry GHG Assessments and Mitigation Planning

Forest GHG assessments typically include a review of GHG emissions from the forest. This can be as simple as assessing the overall forest carbon balance based on forest management planning or as complex as including the GHG impact resulting from silviculture, roads and road building, and tree harvesting impacts on live tree carbon, potentially including target-setting to reduce net emissions or increase forest carbon sequestration. They can potentially consider a full spectrum of carbon and climate implications, from the substitution effects based on the type of harvested wood products (HWP) produced to the ecosystem effects of reflected sunlight on global warming. The **Resources** section includes examples of detailed forestry GHG assessments.

Once a GHG assessment has been completed, a management company can consider developing a climate mitigation plan. This would identify hotspots of GHG emissions from the forest and operations and "low-hanging fruit" opportunities for reducing emissions in ways that combine with other management objectives. Mitigation strategies might include:

- improving equipment management and matching the equipment to the harvest job,
- increasing management intensity so that wood production compensates for reduced harvesting in set-asides, which store additional carbon,
- Implementing new forest health strategies to minimize the carbon and wood fiber lost through tree mortality, or
- Improving the quality of wood merchandizing at harvest operations so that more wood goes into long-lived products.

A plan might include working with vendors, contractors, and public programs to identify common objectives and resources for the cost-effective implementation of key practices. It could also include the integration of any carbon offsets or insets (activities to offset the combined emissions of a company or landowner).

Climate-Smart Considerations

- *Scope:* Assessments may include Scope 1, 2, and 3 emissions, forest carbon storage, and carbon sequestration. Scope 1 includes direct GHG emissions from fossil fuel used in forestry and management operations. Scope 2 includes electricity that might be in offices and occasionally heat from other companies used in kiln-drying wood, in the case of vertically integrated companies. Scope 3 includes upstream emissions from materials and products other than fossil fuels used in forestry and management operations.
- *Uncertainty:* Long-term planning for forest carbon entails using forest carbon models that produce a range of possible future outcomes. Moreover, future impacts of climate change on forest carbon levels are variable, but that variability can be appropriately quantified and used in a decision support scenario with robust modeling. As a result, there is some uncertainty in the long-term planning and management of forest carbon that should be quantified. The impacts of changes in equipment and harvesting practices and sorting logs into long-storing HWP can be more confidentially and reliably predicted and are therefore more certain.
- *Planning Horizon:* Mitigation planning for forests usually occurs over long periods (decades) because of forest carbon storage fluctuations due to harvesting. Planning for operations may have short time horizons for improvements in equipment and harvesting efficiency and long-time horizons when looking to reduce stand damage.
- *Landscape Context:* Managing forest carbon has tradeoffs with wood fiber production and profitability. Forest areas less accessible (e.g., swamps, areas far from mills, steep terrain, and areas of otherwise low operability) may have reduced tradeoffs between carbon and wood fiber, because harvesting and trucking costs may limit the profitability of harvesting timber from these areas. These areas may provide carbon insetting (the reduction of emissions within an organization or operation) opportunities, mitigating emissions that occur upstream and downstream in the supply chain.
- *Ecosystem Benefits:* Forest areas managed for carbon by extending rotations or protecting them from harvesting can also be used to conserve biodiversity, conserve special ecological sites and special sites, and improve water quality. Practices that reduce fuel use also reduce emissions, which impact human health.

Climate-Smart Management Actions

Favorably Ranked Actions

- Avoid forest conversion through policies supporting the enrollment of forest land in current-use taxation programs, state or federal conservation programs, easements, etc. (**Performance Measure 1.3, Indicator 1; SFI Performance Measure 9.2, Indicator 1**).
- Manage forest health and productivity, fire resilience and awareness, and/or other silvicultural or operational practices using the best scientific information to enhance the climate benefits associated with forest operations (**SFI Performance Measure 9.2, Indicator** 1)
- Identify and address opportunities to enhance forest ecosystem resilience to climate change using the best scientific information on company lands, which may include prompt reforestation, planned natural reforestation, or correcting understocked areas (**SFI Performance Measure 9.2, indicator 2**).
- Report or plan to report annually to SFI Inc. measures to mitigate climate change associated with forest operations (**SFI Performance Measure 9.2, Indicator 4**).

Other Actions

- Develop a program to identify and address GHG emissions within your company's operational control (**SFI Performance Measure 9.2, Indicator 3**).
- Conducted a recent system analysis of GHG emissions to identify "hotspots" and opportunities to improve efficiency and reduce emissions.
- Have a company motor vehicle idling policy.

Resources

Cameron, Ryan E., Chris R. Hennigar, David A. MacLean, Greg W. Adams, and Thom A. Erdle. 2013. A Comprehensive Greenhouse Gas Balance for a Forest Company Operating in Northeast North America. Journal of Forestry 111, no. 3: 194–205. https://doi.org/10.5849/jof.12-043 *(an example of forest company GHG emissions analysis).*
Eve, M., D. Pape, M. Flugge, R. Steele, D. Man, M. Riley Gilbert, and S. Biggar, (Eds), 2014. Quantifying Greenhouse Gas Fluxes in Agriculture and Forestry: Methods for Entity Scale Inventory. Technical Bulletin Number 1939. Office of the Chief Economist, U.S. Department of Agriculture, Washington, DC. 606 pages. July 2014 *(an older document on forest GHG emissions accounting methods).*

Helin, T.; Sokka, L.; Soimakallio, S.; Pingoud, K.; Pajula, T. 2013. Approaches for inclusion of forest carbon cycle in life cycle assessment – a review. GCB Bioenergy. 5(5): 475-486 *(provides examples of published life cycle analyses of forest carbon and identifies key considerations).*

Hennigar, Chris; Amos-Binks, Luke; Cameron, Ryan; Gunn, John; MacLean, David A.; Twery, Mark. 2013. ForGATE – A Forest Sector Greenhouse Gas Assessment Tool for Maine: Calibration and Overview. Gen. Tech. Rep. NRS-116. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 54 p *(this model was developed for Maine but is likely applicable across much of the region where spruce-fir and northern hardwoods dominate).*

Kalliokoski, T., Bäck, J., Boy, M., Kulmala, M., Kuusinen, N., Mäkelä, A., Minkkinen, K., Minunno, F., Paasonen, P., Peltoniemi, M. and Taipale, D., 2020. Mitigation impact of different harvest scenarios of Finnish forests that account for albedo, aerosols, and trade-offs of carbon sequestration and avoided emissions. Frontiers in Forests and Global Change, 3, p.562044 *(this paper provides an example of how to include effects of albedo and biogenic on climate impacts, unlike most forest GHG emissions modeling).*

SFI. 2022. Guidance to SFI 2022 Standards and Rules, Section 7. SFI, Arlington. VA *(guidance on climate-smart forestry mitigation [especially resources for quantifying GHG Emissions in forest management operations]).*

Smith, James E.; Heath, Linda S.; Skog, Kenneth E.; Birdsey, Richard A. 2006. Methods for calculating forest ecosystem and harvested carbon with standard estimates for forest types of the United States. Gen. Tech. Rep. NE-343. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 216 p. *(GHG accounting methodology).*

Todd A Ontl and others, Forest Management for Carbon Sequestration and Climate Adaptation, Journal of Forestry, Volume 118, Issue 1, January 2020, Pages 86–101, https://doi.org/10.1093/jofore/fvz062 *(academic but practical lists of adaptation and mitigation strategies/actions).*

Woodall, C. W., Coulston, J. W., Domke, G. M., Walters, B. F., Wear, D. N., Smith, J. E., & Wilson, B. T. T. (2015). The US forest carbon accounting framework: stocks and stock change, 1990-2016. Gen. Tech. Rep. NRS-154. Newtown Square, PA: US Department of Agriculture, Forest Service, Northern Research Station. 49 p., 154, 1-49 *(GHG accounting methodology).*

WRI/WBCSD GHG Protocol. 2022. Land Sector and Removals Guidance, Draft for Pilot Testing and Review, Part 2. Washington, DC: WRI *(GHG accounting methodology, which will be finalized in 2024).*

WRI/WBCSD GHG Protocol. 2022. Land Sector and Removals Guidance, Draft for Pilot Testing and Review, Part 2. Washington, DC: WRI *(GHG accounting methodology, which will be finalized in 2024).*

2.10 FIRE RESILIENCE AND AWARENESS

Background:

Where wildfire is a threat, forest managers aim to limit the susceptibility of forests to undesirable impacts, such as timber loss, loss of private structures, and reduced air quality. They typically seek to minimize the landscape risk of wildfire by helping to raise community awareness of fire benefits, threats, and minimization measures. Wildfire affects less than 0.5% of the landscape each year in this region and has been effectively suppressed in the modern era. Small and modest fires have historically supported fire-adapted natural communities of ecological significance across the region, with the greatest distribution in southern New England. Infrequent fires are likely a factor in the abundance and distribution of the white pine, an economically important species. Large, catastrophic fires in the last two centuries have significantly affected society and fire management policy.

Climate Change and Forest Fire

Climate change is becoming a factor in many parts of the world as it modifies the weather and vegetation conditions suited for fire. Globally, climate change is increasing forest wildfire risks because climate change is projected to raise temperatures, often increase drought risk, and reduce soil moisture in the summer in many regions. It is likely to reduce wildfire risk in some areas, slightly increase it in other places, and vary regionally. Four factors also drive forest fire dynamics: weather and climate, fuels (i.e., flammable vegetation), ignitions, and human activities (e.g., fire management and land use).

Weather and Climate: Pre-settlement fire risk varied with regional climate and forest type, reflecting soil conditions. The paleorecord indicates that fire frequency and impact followed a gradient across the region, where it was more severe in the western part of the region, where the climate is more continental (e.g., hotter, drier summers) and less severe in the eastern portion of the region (e.g., northern Maine and the Maritimes). Similarly, pre-settlement wildfire was more common in southern areas of the region where natural factors – such as dry oak forests, which tended to burn more frequently – and human factors—such as Native Americans, who were more likely to start fires to clear areas for growing crops – were common. Climate change is projected to increase fire risk in the region by up to 50% by mid-century and perhaps as high as 100% by end of century.

Fuels: Forest types and topography vary in their fire regime, which can reflect underlying soil conditions that are prone to fire. Managers can use forest types to help identify the areas most prone to large fires. Most forest ecosystems in the region have some of the lowest levels of natural wildfire disturbance in North America. The region's forests are sometimes called the “asbestos forest.” Fires in northern hardwood forests are rarely ignited and move slowly through the moist litter layer once started. Fire intervals may average more than 3,000 years in most of New England. Other authors suggest a great range of return intervals for northern New England and forests in the nearby Maritime Provinces, with the shortest intervals ranging from 385 to 806 years and the longest intervals ranging from 1200 to 9000 years. Climate change may increase fuel loads due to increased tree mortality from increased drought, pests, and pathogens projected by models. Still, conventional forest management may reduce average forest fuel loads over the long term.

Fire frequency is also a product of local ignition at a site and the resistance of the surrounding landscape to the propagation of fire. Features such as hills, valleys, and water bodies can disrupt the continuity of fuels and moisture regimes. Topographic roughness can reduce the effect of increasing the frequency of human ignition, as many more human ignitions are necessary to maintain a mean fire interval in rough areas compared to less rough areas.

Ignition: Human ignition is the primary cause of fire in the region, ranging from 100% of ignitions in southern New England to about 50% in remote areas of northern New England. Debris burning is a common origin of human-caused ignitions. This leads to fire being most common near settled areas and in the spring before leaf out, when seasonal windy, sunny conditions can dry out leaf litter and small fuels. Human ignitions increase fire frequency in June, July, and August in northern Maine, New Hampshire, New York, and Vermont. Natural ignition from lightning is unlikely to increase wildfire risk significantly. While they are preventable, human ignition levels rise by about 1.7% per year, making it an unpredictable contributing factor for future wildfires. Future wildfires in the region may be as influenced by changes in human ignition behavior as climate change.

Human Activities: The region has a strong fire suppression, such that most fires are small (mostly <1 acre and almost always <50 ha) and of low (<30% biomass loss) to moderate (30–60% biomass loss) severity. The Northeastern Forest Fire Protection Commission pools resources from states and provinces in the region to manage larger fires. Wildfire has a very low per-acre likelihood over long periods, though it is almost twice as frequent on private than public lands.

Climate Change: Fire risk under climate change can be defined as the risk associated with the direct impacts of climate change and associated meteorological patterns that create conditions that favor wildfires, which excludes other important factors. Short-term fire risk indices can incorporate information on weather, fuels (i.e., flammable vegetation), and ignitions, and long-term indices rely entirely on climate projections of weather variables, which are used to estimate average fire risk. As a result, long-term indices may underestimate future fire risk. Climate change is projected to increase fire risk in the region by up to 50% by mid-century and perhaps as high as 100% by 2100.

Climate-Smart Considerations

- *Scope:* Forest managers in the region rely upon state and provincial authorities to control any increased threat of fire driven by climate change. In this region, they depend on the Northeastern Forest Fire Protection Commission to provide wildfire suppression. Managers can pay special attention to forests where fire return intervals are relatively short by managing forest diversity (composition, structure, age class) to reduce risk, infrastructure to create fire-resistant landscapes to reduce wildfire risk/threats using roads as fire breaks, and access for suppression, while controlling fuel loads on high-risk sites (e.g., sandy soils and outwash plains).
- *Uncertainty:* Climate change may not significantly increase the average wildfire threat level. In the near term, increases in catastrophic wildfire risk will be low, but unusual conditions may lead to large uncontrolled fires (e.g., the 2023 Halifax Fire in Nova Scotia). Human activity is a primary source of ignition across most of the region. It may compound the uncertainty of wildfire risk, especially as human-caused wildfire often occurs at lower fuel moisture thresholds than lightning-caused fires.
- *Planning Horizon:* Most studies project that fire risk will not significantly increase until after 2050.
- *Landscape Context:* High-relief areas are less susceptible to wildfire. Areas with a long fire history, especially areas with fire-adapted species (e.g., red and jack pine, big-tooth aspen) and sandy soil or on outwash plains, may have a greater risk.
- *Ecosystem Benefits:* Changes in wildfire levels due to climate may require incorporating climate-smart forestry planning into management for other key forest ecosystem benefits, including water resources, biological diversity, unique cultural and geological values, recreation, visual values, and resources for which Indigenous Peoples' have rights (**SFI Objectives 2 through 6, 8, and 10**). Some wildfire species may benefit from wildfire (e.g., black-backed woodpecker, early-successional species).

Climate-Smart Management Actions

Favorably Ranked Actions

[NONE: Managers did not identify or recommend any actions that were practical and/or in use.]

Other Actions

- Have a program to ensure that field staff have current firefighting training from a state forestry department or a federal basic fire training school.
- Apply a fire control program that evaluates the additional risk of undesirable wildfire posed by climate change on the company's and adjacent forest lands.
- Apply or foster practices that remove harvest residue to reduce the risk of GHG emissions from catastrophic fires.
- Use stand- and landscape-level management strategies to mitigate any additional risk of undesirable wildfire due to climate change (e.g., use additional prescribed fire, cultural burning, thinning, or hazardous fuel reduction in atypical areas or times due to climate change).
- Apply practices to mitigate the negative impacts of extreme wildfire on water and soils and to promote forest restoration

and future forest resilience in these areas.

- Restore or maintain fire in fire-adapted ecosystems.
- Maintain or improve the ability of forests to resist pests (e.g., spruce budworm) that may alter fuel regimes.
- Alter forest structure and composition to reduce the risk and spread of unacceptably severe fire.
- Implement various management activities or silvicultural prescriptions across areas with similar starting conditions to diversify forest conditions and evaluate different management approaches.
- Establish or maintain fuel breaks in strategic locations to stop the spread of unacceptable fire.
- Actively promote broad social awareness and increase education about fire safety to reduce human ignitions and the anticipated effects of climate change on fire regimes.

Resources

Dillon, Gregory K.; Menakis, James; Fay, Frank. 2015. Wildland fire potential: A tool for assessing wildfire risk and fuels management needs. In: Keane, Robert E.; Jolly, Matt; Parsons, Russell; Riley, Karin. Proceedings of the large wildland fires conference; May 19-23, 2014; Missoula, MT. Proc. RMRS-P-73. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. p. 60-76 *(provides a widely used framework for assessing wildlife risk and fuels management).*

LANDFIRE: LANDFIRE Existing Vegetation Type layer. (2013, June - last update). U.S. Department of Interior, Geological Survey, and USDA [accessed online 5/2/2023 at: http://landfire.cr.usgs.gov/viewer/ *(online mapping tool and data portal for data on estimate vegetation fire return intervals, fire severity, and fuel loads which may help identify spatial fire risk patterns).*

2.11 LEGAL REGULATORY COMPLIANCE

Background:

Sustainable businesses comply with all applicable international, federal, provincial, state, and local laws and regulations. This requires an awareness of the relevant regulations and laws, a process for achieving and maintaining compliance, and the necessary documentation of regulatory actions (e.g., permits).[i]

Climate Change Impacts on Legal and Regulatory Environments

Most people in the U.S. and Canada believe climate change is real and support climate action. As a result, climate change is increasingly becoming part of the regulatory arena. Climate change poses significant transitional risks and opportunities for commercial landowners as regulatory policy responds to climate change. The SEC (U.S) has proposed major regulatory changes to require that publicly traded forestry companies release disclosures about their response to climate change. Greater voluntary and regulatory requirements for climate change disclosures are expected. U.S. and Canadian policies are progressing rapidly toward addressing climate change, though abrupt policy shifts may occur following future elections in the U.S. and Canada. The USDA and other U.S. agencies are expanding their climate policy to reduce internal emissions and support greater resiliency in their activity areas.

However, climate change is of low importance to voters relative to other policy issues (e.g., the economy and health care). As a result, state and provincial governments in the region are implementing climate change forestry strategies that vary in effectiveness. None have enacted climate change regulations that directly affect forest management. Climate change will likely result in modifications of state-level water quality best management practices (BMPs) due to increases in extreme rainfall events in some areas. Significant, unpredictable extreme events associated with climate change (e.g., 2011 Tropical Storm Irene in Vermont, 2023 Province of Quebec Wildfires, 2023 Halifax Wildfire in Nova Scotia) may result in short-lived but high levels of climate policy activity at the state or provincial level. Future forest land-use regulations may focus on avoiding conversion/deforestation – because it has consistent climate benefits – and less on forest practices. After all, forest management regulations often have inconsistent benefits.

The states use state forest plans (SFPs), wildlife action plans (SWAPs), and statewide comprehensive outdoor recreation plans (SCORPs) to receive federal funding, since federal funding requires plans to address climate change. States and provinces in the region also have climate action plans. These ongoing policy efforts have strategies related to forest management (e.g., land use, fire management, water quality, employee working conditions, wildlife conservation, and emissions from equipment) that may influence the revision of new regulations.

Climate-Smart Considerations

- Scope: Commercial forest management companies must comply with applicable federal, provincial, state, or local laws and regulations – including those that address climate change – though a lack of regulatory guidance may impact compliance. They have limited control over policy and regulation, though they can stay abreast of climate policy and have their representatives participate in policy-making discussions related to climate change.
- *Uncertainty:* Climate change is of low importance to voters relative to other policy issues (e.g., economy, health care). However, significant, unpredictable extreme events that may be associated with climate change (e.g., 2011 Tropical Storm Irene in Vermont, 2023 Province of Quebec Wildfires, 2023 Halifax Wildfire in Nova Scotia) may result in short-lived but high levels of climate policy activity at the state or provincial level.
- *Planning Horizons:* The policy arena and impacts of climate

[i]NOTE: The material in this section labelled Legal and Regulatory Compliance is not considered legal advice and as always, you will need to do your own research to make your own conclusions with regard to the laws of your jurisdiction. In no event will Manomet, Maine TREE, or SFI be liable for any direct, indirect, or consequential damages resulting from the use of this material. Readers are encouraged to seek suitable legal counsel over all legal materials related to the materials in this Manual.

change on the policy arena are unpredictable beyond the short-term (< five years).

- *Landowner Context:* Smaller land managers and logging companies may have limited financial capacity to comply with new regulations and influence climate change policy and rule-making associated with climate change. U.S. publicly traded companies may need to meet future SEC requirements regarding climate change disclosures on risk mitigation, GHG emissions, climate-related targets and goals, and transition plans (if any).
- *Other Benefits:* Changes in forest policy call for new research, models, and synthesis that can inform forest managers about climate-smart forest management, including management for wood fiber, water quality, recreation, and wildlife (**SFI Objectives 2 through 5**).

Climate-Smart Management Actions
Favorably Ranked Actions
[NONE: Managers did not identify or recommend any actions that were practical and/or in use.]

Other Actions
- Report Scope 1 and Scope 2 GHG emissions to the appropriate authorities when required by law or regulation.
- Monitor for changes in applicable international, federal, provincial, state, and local climate laws, statutes, and regulations and comply with these changes.

Resources
Congressional Research Service. 2021. U.S. Climate Change Policy. R46947. Congressional Research Service, Washington, D.C. *(summarizes federal climate change policy efforts).*

National Association of State Foresters. 2023 State Forest Plans. Web site accessed on 5/1/2023 at: https://www.stateforesters.org/forest-action-plans/ *(provides links to state forest plans).*

2.12 FOREST RESEARCH, SCIENCE, AND TECHNOLOGY

Background:
Investing in research and technology can help ensure that the most suitable solutions are available and appropriately applied for effective forest management decisions. This can include providing in-kind support or funding for long-term sustainable forest management research, participating in forestry research, sharing research findings with others to advance sustainable forestry, and supporting science communication that summarizes science and provides management guidance.

Climate Change and Forestry Research, Science, and Technology
Climate change is an unprecedented threat that is increasing demands for new information and scientific research. Investing in climate change research and technology can help advance the local and regional understanding of climate-smart forestry and improve the practice. Participation in research by forestry companies can help ensure that the science is credible and valuable to forest managers.

The complexity of climate change makes it challenging to set priorities for practical new forestry research. Unpredictable economic factors make it difficult to identify what research will help manage forests and wood fiber for future markets and address investor demands and labor constraints. Current forest health threats are increasing, and amplification by climate change varies regionally from negligible to severe. The range of climate scenarios and projected impacts make it difficult to predict when and how to apply different forestry actions in the future to manage forest ecosystem changes. Research efforts in the short-term should prioritize cost-effective strategies that aim to enhance tree vigor and promote tree species that can increase forest resilience. In the long term, research should produce robust strategies to overcome uncertainties and improve forest resilience in response to various projected climate change scenarios.

A declining forest research funding pool, which is increasingly focused on sustainable forestry's environmental and social dimensions, results in less funding for applied climate-smart silvicultural and engineering research. Collaborative programs like regional research cooperatives help leverage limited funding into practical regional forestry research. Despite challenges, climate-smart forestry research publications have rapidly grown in the last decade.

Direction of Climate-Smart Forest Research
The direction of climate-smart forestry is being shaped by:
(1) Pressure from supply chains (sustainability claims), investors (disclosure pressures), and forest public policy initiatives (e.g., EU carbon tax) to improve the management and reporting of greenhouse gas and climate risk.
(2) The uncertain conditions of future forest ecosystems due to climate change, including modest changes that are already occurring.
(3) New technologies and analytical techniques that allow scientists to collect, analyze, and predict outcomes based on big data.

As a result, climate-smart forestry is advancing research in four major areas, aimed at:
(1) *Risk management research*, which develops management practices to improve forest resilience to climate disturbances such as drought, warmer winters, new pests, and intense rain or snow.
(2) *Improving and reducing the costs of forest carbon accounting* (e.g., inventorying, monitoring, reporting, and verification or MRV), which supports the ability of the forest to adjust to changes in climate.
(3) *Enhancing precision forestry* to increase the efficiency of wood fiber production, reduce the greenhouse gas (GHG) intensity of wood fiber, and support sustainable

intensification and mitigation potential.
(4) *New social science* to gauge public acceptance of precision forestry, new technologies, and climate-smart forestry and achieve social acceptance and license. Although climate-smart science is advancing, much research focuses on maintaining current ecological patterns. Few studies evaluate active or transformational treatments that may become important in the coming decades.

Risk management research aims to apply new analytical techniques and silvicultural approaches to better manage risk and ecosystem resilience. Conventional empirical forest models are combined with process-based ecosystem models to better predict growth, yield, and forest carbon under future conditions. Researchers are developing machine learning and other analytic techniques to help spatially predict risk and detect climate impacts. Researchers are also testing new approaches and practices to ensure that silviculture can actively meet rapidly changing environmental conditions.

New markets support research to improve carbon monitoring, measuring, reporting, and verification (MMRV), develop new climate-smart products, and create revenue streams by marketing ecosystem services such as carbon and biodiversity. MMRV research focuses on improving the monitoring and verification of on-the-ground carbon and chain of custody using forest inventory data, remote sensing data, and AI.

Research on improving wood production underpins the growth of precision forestry. It is leading to the development of new remote and ground sensors to more cheaply gather large forest monitoring data sets, new techniques to process such data statistically, artificial intelligence (AI) and other machine learning techniques to analyze data, improved forest models, and digital networks (including GIS) and technology to improve planning, logistics, and decision making in management and harvesting. Precision forestry can enhance wood growth and harvesting efficiencies, making managing complex stands easier and reducing forestry costs and impacts, improving forest resilience as a result. Harvest machines already have digital systems to map stand conditions and monitor harvest and machinery productivity. LiDAR technology is increasingly used for monitoring timber, forest fires, pest and disease outbreaks, and producing water-flow maps of sensitive wet areas. Drones (UAVs) can conduct surveillance, mapping, and silvicultural operations, such as fertilizing seedlings and controlling weeds, pests, and diseases.

You can contact regional forestry research cooperatives, land grant universities, and forestry schools to identify opportunities to participate and support climate-smart forestry in your region and encourage knowledge transfer of climate-smart forestry research from scientists to employees and others. Forest landowners can communicate climate-smart forestry priorities to researchers at regional forestry research cooperatives, land grant universities, and universities with forestry schools.

Climate-Smart Considerations

- *Scope:* Commercial forest management companies can support forest management research, science, and technology projects through advising, funding universities and research organizations, and providing field data and research sites. By serving on research advisory boards, they can help direct research to focus on the most relevant climate change topics.
- *Uncertainty:* Funding availability may be uncertain because long-term national support for climate change research is of low importance to voters relative to other policy issues (e.g., economy, health care), and political parties vary in how they prioritize climate research. Significant, unpredictable extreme events associated with climate change (e.g., 2011 Tropical Storm Irene in Vermont, 2023 Halifax Wildfire in Nova Scotia) may result in short bursts of regional climate funding.
- *Time Horizons:* Most climate change research projects are three to five years, so the policy arena and the impacts of climate change on the policy arena are unpredictable beyond the short-term (less than five years). Needed long-term research is complex to fund.
- *Landowner Context:* Small forest management companies may have limited staff capacity and funding for participating in climate-smart forestry research, though they can make study sites available to researchers.
- *Other Benefits:* New research, models, and synthesis could inform forest managers about climate-smart management for planning, forest health, water quality, recreation, wildlife, fire management, and climate change (**SFI Objectives 1 through 5, 7, and 9**).

Climate-Smart Management Actions

Favorably Ranked Actions
- Provide financial or in-kind support for research, collaborations, or knowledge transfers that address climate change adaptation and mitigation as identified by your company, local stakeholders, communities, and/or Indigenous Peoples.
- Share knowledge from collaborative climate change forestry research to influence sustainable forest management positively.
- Participate individually and through cooperative efforts at the national, state, provincial, or regional level in developing technical and guidance forestry information for managing climate change through adaptation and mitigation.

Other Actions
- Support research on assisted migration, climate impact assessments, and modeling trees and forests in response to climate change.
- Assess the implications of climate change on forest management at multiple scales.
- Support the development of methods for climate-based seed transfer, species selection, and stocking standards.
- Promote the knowledge transfer of climate modeling science, the modeling of tree and forest response to climate change, and assessment tools and techniques to forest company staff.

Resources

Regional forestry research cooperatives, land grant universities, and forestry schools can be contacted to identify opportunities to participate and support climate-smart forestry in your region. Landowners can communicate climate-smart forestry priorities to researchers at regional forestry research cooperatives, land grant universities, and forestry schools.

Resources for knowledge transfer are available from the USDA Northern Forests Climate Hub (vulnerability analysis and assessment tools), the U.S Forest Service's Climate Change Tree Atlas (for understanding tree migration the national Adaptive Silviculture for Climate Change project, Manomet's Climate Smart Land Network, the University of Maine System's Maine Climate and Ag Network (MECAN) and Forest Climate Change Initiative, the Northeast Society of American Foresters (which hosts practical workshops on topics including climate-smart forestry), and Forest Stewardship Guild (which hosts field trips on climate change and forestry).

2.13 TRAINING AND EDUCATION

Background:
In sustainable forestry, appropriate training and education for employees, contractors, and professional logging contractors are essential to help workers understand and fulfill their assigned roles and responsibilities, especially for forest certification. They are necessary steps for ensuring the continual improvement of forestry workers. They also ensure that forestry workers understand and can comply with relevant regulations and laws for labor (e.g., worker safety regulations) and the environment (e.g., local water quality regulations, U.S. Endangered Species Act, Canadian Species at Risk Act). Training can also improve the sustainable forestry expertise of professional logging contractors in certification principles, transportation, and awareness of emerging technologies, safety, protecting water quality and road management, and conserving wildlife habitats and rare natural forest communities.

Climate Change and Training and Education
Climate change affects the forest and working environment, and its impacts on the business sector influence forest management policy (including forest certification) and business sector practices. Workers need training on when and how to manage climate impacts such as severe flooding, their roles and responsibilities for meeting certification requirements for climate-smart forestry (i.e., **SFI Objective 9**) and other reporting activities, and how to minimize exposure to the human health risks that are increased by climate change.

Training for Roles and Responsibilities
Training on climate-related responsibilities is critical to help employees and workers understand and respond to climate change, **SFI Objective 9**, and their associated new job roles and responsibilities. Once employees have been assigned job roles and responsibilities for **SFI Objective 9**, the climate-smart forestry training needs can be identified for each employee (**SFI Performance Measure 13.1, Indicator 2**). Most responsibilities are planning and reporting functions that may be the responsibility of forest planning and certification staff, while field employees may implement a company's mitigation and adaptation plans.

Climate training is highly challenging because the effectiveness of adaptation strategies is uncertain, and climate information is complex. Both are significant obstacles to forest workers learning about and applying climate-smart forest actions and practices.

Employees may need training on adaptation planning and reporting (**SFI Performance Measure 9.1**), which may include training on how to conduct a vulnerability analysis, develop a climate adaptation plan, identify company strategies that align with existing regional climate adaptation plans (e.g., relevant state wildlife action plans, state forest action plans, state adaptation plans, and provincial adaptation plans), and report annual progress on adaptation to SFI.

Employees may also need training in mitigation management (**SFI Performance Measure 9.2**). This could include training on how to identify climate mitigation opportunities associated with forest management operations, which could consist of managing forest health and productivity (**SFI Objective 2**), fire resilience and awareness (**SFI Objective 10**), and other practices that enhance climate benefits (e.g., set-asides and long rotation forestry areas for water quality (**SFI Objective 3**) and wildlife (**SFI Objective 4**). Training might be necessary to identify opportunities to enhance forest ecosystem resilience through prompt reforestation, managing for adequate regeneration, considering appropriate afforestation, protecting advance regeneration during regeneration treatments, and selecting and favoring crop trees in stand tending treatments. It may also be necessary to develop a standardized monitoring program to identify and manage greenhouse gas (GHG) emissions and report annual progress on mitigation to SFI. Organizations such as regional forestry research cooperatives, land grant universities, and forestry schools often provide climate-smart forestry training opportunities to professionals through workshops, tours, and courses.

Health Training
Climate change will increase the health risks posed to outdoor workers through hot weather, low air quality, and exposure to insect-borne diseases. Heat-related health problems such as heat exhaustion, heat stroke, and exacerbated respiratory diseases are slated to increase with climate change. Levels of ozone and fine particles (PM 2.5) from urban areas and wildfire smoke have been increasing seasonally and will further increase.

Lyme disease and other tick-borne diseases are an occupational hazard for forestry workers and are increasing in incidence and expanding northward with a warming climate as a critical driver. Many infected people are more likely to discontinue working or work part-time. Lyme disease has emerged as a worker compensation issue for outdoor workers in Maine, mostly among landscapers in southern Maine. Mosquito-borne diseases are also expanding north with climate change and pose a risk to outdoor workers. Training to increase awareness and the use of risk-reduction measures can substantially reduce the risk of contracting Lyme and other tick-borne diseases.

The U.S. Occupational Safety and Health Administration, U.S. CDC, state agencies, and the Canadian Centre for Occupational Health and Safety have information on climate-related health risks.

Climate-Smart Considerations

- *Scope:* Training for **SFI Objective 9** is only necessary for employees and forest workers assigned roles and responsibilities for **SFI Objective 9**.
- *Uncertainty:* Training effectiveness for climate-smart forestry can be undermined when training emphasizes the uncertainty of effective adaptation strategies and the complexity of climate information. Training focused on reducing complexity can help employees overcome these barriers. It can also focus on practical considerations that individual employees are responsible for, such as forest health and useful water quality management strategies.
- *Planning Horizons:* Training and education should focus primarily on near-term climate impacts and available practical solutions. For long-term impacts, training and education should focus on building awareness about the anticipated effects and intensity, using existing internal and public data to anticipate change, and developing robust strategies to address uncertainty.
- *Landowner Context:* Small forest management companies and logging contractors can reduce training costs by using training workshops and materials provided by organizations listed in the resources section.
- *Other Benefits:* Adaptation and mitigation training can improve forest resilience for water quality, recreation, and wildlife (**SFI Objectives 1 through 8**).

Climate-Smart Management Actions

Favorably Ranked Actions

- Provide appropriate training to personnel and contractors to fulfill their climate change responsibilities under the SFI or other sustainability programs and appropriately apply climate-smart practices.
- Participate in or support SFI Implementation Committees (SICs) and other bodies that create and deliver guidance and training on climate-smart forestry best management practices.
- Provide employee training on health-related factors exacerbated by climate change, such as heat stress and insect-borne diseases.

Other Actions

- Provide specialized labor training for logging contractors harvesting disturbed stands (e.g., on salvage, pre-salvage, and sanitation logging).

Resources

Climate Change Training Resources

United States

Federal Government resources: For USDA, companies can consult with the USDA Northern Forests Climate Hub *(training and materials on climate impacts, vulnerability analysis, and assessment tools)*, the U.S Forest Service's Climate Change Tree Atlas *(for materials on understanding tree migration),* the U.S. Forest Service's national Adaptive Silviculture for Climate Change (ASCC) project *(for materials on adaptive silviculture),* the U.S. Forest Service Bartlett Experimental Forest *(silvicultural training)*, and the U.S. Forest Service Penobscot Experimental Forest *(silvicultural training).*

Universities: Companies can consult with faculty with the UMaine School of Forest Resources *(silvicultural research, modeling, and training)*, the UMaine Center for Research on Sustainable Forests *(silvicultural training, materials, modeling, climate change research, webinars)*, the UMaine Cooperative Forestry Research Unit *(silvicultural training, materials, research)*, the UNH Department of Natural Resources and the Environment *(research)*, the SUNY ESF Climate and Applied Forest Research Institute *(research)* and the UVM Rubenstein School Forestry Program *(silvicultural training, materials, and applied research)*. The University of Maine system has programs for northern hardwood, white pine, and spruce-fir silviculture, while other universities mainly focus on hardwood and pine silviculture.

Other regional organizations: Companies can consult with Manomet's Climate Smart Land Network *(materials, training, and applied forest research)*, the Northeast Society of American Foresters *(practical silvicultural workshops)*, Forest Stewardship Guild *(practical silvicultural workshops)*, Maine Tree Foundation *(workshops)*, SFI State Implementation Committees *(SICs, practical workshops),* Hubbard Brook Foundation *(workshops, research)*, New England Forestry Foundation *(workshops)*, and Woodwell Climate Research Center *(forest carbon and risk assessment research).*

Canada

Canadian Government: Companies can consult with staff at Natural Resources Canada and its research centers: the Canadian Forest Service Atlantic Forestry Centre *(NB, forest ecosystem climate research and modeling)*, the Acadia Research Forest (NB), and Laurentian Forestry Centre *(PQ, forest ecosystem modelling, silvicultural research, decision support tools)*

Universities: Companies can consult with faculty at the Université de Moncton École de foresterie *(research),* UNB Fredericton School of Forestry Environmental Management *(forest ecosystem and silvicultural research),* Université Laval Département des sciences du bois et de la forêt and Chaire en génomique forestière et environnementale *(genomics, forest and climate research, plantation forestry)*

Other regional organizations: Northern Hardwoods Research Institute *(research, modelling, workshops)* and Maritime College of Forest Technology *(workshops).*

Workers Heat and Insect Borne Disease Resources

U.S. Occupational Safety and Health Administration has handouts and videos on training outdoor workers for heat and tick-borne

Diseases. State health agencies and the US CDC have tick-borne disease prevention materials.

Canadian Centre for Occupational Health and Safety has handouts on Lyme's diseases and hot environments.

2.14 COMMUNITY INVOLVEMENT AND LANDOWNER OUTREACH

Background:
Education about the principles of forest sustainability that is aimed at the public and landowners increases public awareness about the benefits of forests and sustainable forest management. This activity can include engaging different stakeholder groups representing SFI-certified companies, foresters, government agencies, professional societies, conservation organizations, Indigenous Peoples and their governments, community groups, sporting organizations, labor groups, universities, extension agencies, the American Tree Farm System®, and other landowner cooperative programs. Outreach can include working alone through support programs or SFI Implementation Committees for (1) education and outreach on sustainable forestry actions and practices to forest landowners, (2) conservation of managed forests through voluntary policies and programs, (3) feedback efforts from the public when management appears inconsistent with the SFI Standards principles and objectives. These efforts can use different media for public outreach and education and to communicate about sustainable forest management.

Climate Change and Community and Landowner Outreach
Communication and outreach on climate-smart forestry with public, professional, and landowner groups is challenging because of the uncertainty and complexity of climate sciences, the wide ranges of public attitudes, and the need for different communication strategies for various audiences. Forest carbon management is incredibly complex and may require special attention to effectively communicate sequestration, permanence, additionality, and leakage tradeoffs. The uncertainty and complexity of climate sciences can be reduced as a barrier by focusing on well-understood phenomena and practical considerations such as forest health and practical climate-smart forestry actions.

Communication and outreach for climate-smart forestry may be most effective if they draw on narratives from foresters and other field workers who have direct experience with climate impacts. This might include addressing key questions such as: "Why climate-smart forestry?" "When does climate-smart forestry make sense?" "What are climate-smart forestry practices that make sense locally?" "How do we apply climate-smart forestry practices?"

Many stakeholder views on climate-smart forestry reflect their ongoing perspective on forest policy values and conflicts. Their existing viewpoints can strongly influence their acceptance of different climate-smart forestry practices with little regard to their effectiveness for climate resilience or mitigation potential. The general public attitudes about climate change vary greatly and can range from alarmed to dismissive across different regions. With "alarmed" and "concerned" public and landowners, public outreach on climate-smart forestry may bolster a company's social license by showing that it is knowledgeable and attentive to current forest threats and can apply appropriate, practical solutions. With dismissive stakeholders, the messages might focus on no-regrets or low-cost forest health actions that have positive impacts under all conditions.

Climate-Smart Considerations

- *Scope:* Commercial forest management companies should understand community and stakeholder perceptions of climate change and forest management. This knowledge and information can inform outreach efforts to improve public and stakeholder engagement and support of climate-smart forestry approaches.
- *Other Benefits:* Communication and outreach to the public, professionals, and landowners can help advance practical climate-smart forestry across the region. This can help build public confidence that managed forests are part of the solution to climate change.

Climate-Smart Management Actions
Favorably Ranked Actions

- Support – individually and through cooperative efforts involving SICs, education, and outreach to forest landowners on climate-smart forestry – best management practices to achieve SFI objectives.

Other Actions

- Participate in efforts to support or promote climate mitigation by avoiding the conversion of managed forests through voluntary programs such as Forest Legacy Programs, conservation easements, federal, state, or provincial cost-share programs, or SFI Conservation Grants.
- Communicate with abutting landowners about climate risks, especially about wildfire risk, if appropriate.
- Share climate adaptation and mitigation plans with other landowners and the public.
- Actively promote broad social awareness and increase education by supporting programs like FireWise USA, Community Wildfire Protection Plans, Fire Adapted Communities, and other community programs about fire safety to reduce human ignitions and the anticipated effects of climate change on fire regimes.

Resources
Maine Climate Table. 2017. Communicating with Mainers on Climate Change. Prepared by Goodwin Simon Strategic Research on behalf of the Maine Climate Table *(addresses many topics beyond forestry and relevant to northeastern rural areas)*

Marlon, J.R., Wang, X., Bergquist, P., Howe, P.D., Leiserowitz, A., Maibach, E., Mildenberger, M. and Rosenthal, S., 2022. Change in US state-level public opinion about climate change: 2008–2020. Environmental Research Letters, 17(12), p.124046 *(quick summary of state-level changes in public attitudes about climate change to help understand audience).*

Pew Research Center, September 2021. In Response to Climate Change, Citizens in Advanced Economies Are Willing To Alter How They Live and Work. Pew Research Center, Washington, D.C. *(survey results for U.S. and Canada on public attitudes about climate change, broken out by sex, age, and political leaning that can help readers identify messages for communicating with different audiences).*

Simon, A. J. Whaley, E. Rogers, and C. Lee, Maine Climate Table. 2019. Communications 101: Developing Persuasive Communications about Climate Change in Maine. Maine Climate Table *(similar to Maine Climate Table (2017) but in short form. It addresses many topics beyond forestry but is short and relevant to northeastern rural areas).*

2.15 PUBLIC LAND MANAGEMENT RESPONSIBILITIES

Background:

Public agencies manage most state and federal lands in the United States. Some state agencies elect to enroll state forestland that is managed for wood products in SFI. Each state has a different forest management process managed by one or more land management agencies. Typically, managing wildlife conservation areas, recreational areas, and managed forestlands is handled by more than a single agency. State agencies usually have stakeholder advisory committees to oversee the planning process, technical committees to ensure management planning soundness, and public hearings so that the public can participate and weigh in on forest management plans and activities.

In Canada, forestry companies can hold forestry licenses on Canadian provincial and federal crown lands that permit timber harvesting in a fixed area or volume for a fixed period. The planning process for Crown Lands in Canada includes opportunities for engaging governmental entities and public stakeholders. It provides options for engaging with local stakeholders over forest management issues through provincial or independent collaboration. Under forest management, stakeholder engagement processes for Crown Lands have varied in eastern Canadian provinces. New Brunswick and Nova Scotia stakeholders have favorably rated public planning processes for Crown Lands under forest management, but outcomes have created conflicts among stakeholder groups. Many stakeholders agree to improve the public involvement processes to achieve greater trust. Independent efforts can include meetings with community leaders, town halls, in-person meetings, social media, newsletters, and public opinion surveys.

Climate Change and Public Land Management Responsibility

Many stakeholder attitudes reflect ongoing forest policy values and conflicts. These existing views largely determine the acceptability of different climate-smart forestry practices, with little regard to their efficacy. Direct engagement from forest managers of public forestland about various climate change resilience and mitigation strategies may help achieve social acceptance and license. A key challenge is to keep complexity and uncertainty from encumbering the planning process. Forest carbon management is incredibly complex, and it may require special attention to communicate tradeoffs in sequestration, permanence, additionality, and leakage.

Canada

Forest policy in New Brunswick and Nova Scotia is unsettled because of stakeholder conflicts. Climate change issues may increase these conflicts about forest management on Crown Lands, as some stakeholders may advocate for reducing the production of forests to increase sequestration and carbon storage on Crown Land forests in New Brunswick and Nova Scotia. Both provinces lack specific climate mandates for Crown Lands. However, mandates for growing reserve areas and restricting intensive forest management on Crown Lands may affect their forest resilience and mitigation potential.

In New Brunswick, the Forest Management Plan (Schedule C) covers a 25-year plan period and includes an 80-year growth projection. Past provincial objectives for New Brunswick have included provision for long-term forest health and old forests, which can readily overlap with climate-smart forestry objectives for climate change resilience and mitigation. How SFI certificate holders that manage Crown Lands address climate-smart forestry under SFI Objective 9 may be controversial. Some stakeholders may prefer extensive management for old forests and continuous cover forestry over intensive management to achieve climate mitigation goals.

In Nova Scotia, the Crown Lands Act (R.S., c. 114, s. 1.) requires that “Crown lands are sustainably used, protected, and managed to maintain and enhance biodiversity and consider climate change.” Emerging forest policy may limit clearcutting and other intensive forestry practices on Crown Lands.

United States

Stakeholder conflicts regarding forest management on state lands vary among regional states. For forest management of public state lands in the United States, some but not all advisory and technical committee members may have climate change knowledge in their area of expertise. Land managing agencies may need additional training to ensure that advisory committees and technical committees are well informed about climate change’s impacts on forests, forest carbon science, and how to plan and manage for impacts and carbon.

Climate-Smart Considerations

- *Scope:* Commercial forest management companies operating on Crown Lands must comply with provincial requirements for engaging and consulting with forest stakeholders. State and provincial agencies that manage forests must also conform with public forest land planning requirements. Both may need to consider how climate change and forest carbon consideration affect public land management and how to effectively communicate key points to advisory and technical committee members and the public so that they are informed, but not overwhelmed. Debates about managing forest carbon on public lands are likely to intensify.

- *Planning Horizons:* Although both Canadian provinces have provisions for long-term (>20 years) forest management plans, changes in the provincial policy arena may be unpredictable beyond the short-term (< five years). The State of Maine's Bureau of Public Lands has a 15-year planning horizon.
- *Others:* Changes in forest policy call for new research, models, and synthesis that can inform forest managers about climate-smart forest management, including management for forest health, water quality, recreation, wildlife, and wood fiber (**SFI Objectives 2 through 5 and Objective 7**).

Climate-Smart Management Actions

Favorably Ranked Actions

[NONE: Managers did not identify or recommend any actions that were practical and/or in use.]

Other Actions

- Participate in public land planning and management activities that support applying climate-smart forestry practices and activities on public lands.

Resources

AccountAbility. 2015. AA1000SES Stakeholder Engagement Standard 2015. AccountAbility, London, UK (general guidance for engaging stakeholders, processes may be suitable for large companies).

AccountAbility. 2018. AA1000APS Accountability Principles 2018. AccountAbility, London, UK *(general guidance for identifying materiality issues on which to engage stakeholders, the process may be suitable for large companies).*

Janowiak, M., K. Schmitt, D. Shannon, P. Leopold, L. Brandt, S. Handler, T. Ontl, C. Peterson, C. Swanston. 2022. A Quick Guide to Adaptation Planning for Natural Resource Professionals. Northern Institute of Applied Climate Science, and USDA Northern Forests Climate Hub *(a quick guide to understanding the basics of climate adaptation planning).*

Todd A Ontl and others, Forest Management for Carbon Sequestration and Climate Adaptation, Journal of Forestry, Volume 118, Issue 1, January 2020, Pages 86–101, https://doi.org/10.1093/jofore/fvz062 *(academic but practical lists of adaptation and mitigation strategies/actions).*

2.16 COMMUNICATIONS AND PUBLIC REPORTING

Background:

Reporting the results of third-party audits within certification fulfills several functions. (1) Concise public reports can communicate essential information about a landowner's efforts at sustainability forestry, which can increase the public's understanding of and support for forest certification. (2) They concisely describe to SFI administrators the level of conformance and non-conformance with certification indicators, needed corrective action plans, opportunities for improvement, and exceptional management. (3) They provide feedback to company staff where management successfully meets certification objectives, needs improvement now or in the future, or is exemplary.

Climate Change and Communication

Climate change does not directly affect communications and the reporting of audit results, though the new SFI 2022 Standards and Rules requirements, including the new **SFI Objective 9: Climate Smart Forestry**, add to SFI reporting requirements. Third-party audit reports for the SFI 2022 Standards and Rules now need to indicate conformance and non-conformance, required corrective action plans, opportunities for improvement, and exceptional management concerning Objective 9 climate-smart forestry indicators. Third-party audit reports can be used to help communicate the need for and the exercise of practical climate-smart forestry to the public and to help other forest landowners become aware of how climate-smart forestry can practically be applied to achieve their management goals (**SFI Objective 14: Community Involvement and Landowner Outreach**).

The general public's attitudes about climate change vary and can range from alarmed to dismissive across different regions. With select stakeholders (e.g., "alarmed" or "concerned"), public reporting on climate-smart forestry may bolster a company's social license to operate by showing that it is knowledgeable and attentive to current forest threats and climate mitigation and able to apply appropriate, practical solutions. Company communication and messaging about climate change may be most persuasive if they draw on narratives from people who have direct experience with climate impacts.

Companies must complete the SFI annual progress report survey, including survey questions about climate-smart forestry related to Performance Measure 9.1, Indicator 4. Third-party audit reports and the SFI annual progress report survey can be used in a company's process for the continuous improvement of climate-smart forestry (**SFI Objective 17**). They can help companies make claims in other reporting systems (e.g., CDP, Global Reporting Initiative, Sustainability Accounting Standards Board) to demonstrate to supply chains, shareholders, and investors their commitment to reducing climate risk to forest resources and supporting climate mitigation.

Climate-Smart Considerations

- *Scope:* Certified forest management companies must report on climate-smart forestry in third-party audits described in **SFI Objective 9: Climate Smart Forestry** and complete the SFI annual progress report survey.

- *Planning Horizons:* Third-party auditing typically begins twelve to eighteen months before reporting every five years. The SFI annual progress report survey is conducted annually, but it can require more than a month to assemble the information necessary to complete the survey.
- *Landowner Context:* Smaller forest companies have limited capacities for extensive conformance with **SFI Objective 9**, so audit reports and surveys may reflect limited action on climate-smart forestry.
- *Other Benefits*: Information from third-party audit reports and the SFI annual progress report survey can communicate practical progress on climate-smart forest management to employees, the public, forest landowners, and clients. This can help build public confidence that forestry is part of the solution to the impacts of climate change.

Climate-Smart Management Actions

Favorably Ranked Actions

- Include a summary of climate-smart forestry activities in the summary audit report prepared by the certification body for SFI.

Other Actions

- Report or plan to report annually to SFI progress toward achieving climate change adaptation strategies and plans.
- Report or plan to report annually to SFI measures to mitigate climate change associated with forest operations.

Resources

Holmgren, P. and Kolar, K., 2019. Reporting the overall climate impact of a forestry corporation-the case of SCA. URL https://mb.cision.com/Main/600/2752801/999695.pdf *(a case study of forestry company reporting on climate).*

Leiserowitz, A., Roser-Renouf, C., Marlon, J. and Maibach, E., 2021. Global Warming's Six Americas: a review and recommendations for climate change communication. Current Opinion in Behavioral Sciences, 42, pp.97-103 *(identifies six key segments of U.S. stakeholders and their views on climate beliefs, which may be helpful for public communications.)*

Seddon, N., Smith, A., Smith, P., Key, I., Chausson, A., Girardin, C., House, J., Srivastava, S. and Turner, B., 2021. Getting the message right on nature-based solutions to climate change. Global change biology, 27(8), pp.1518-1546 *(academic, identifies a way to improve public messaging of nature-based forestry solutions).*

Large companies can review corporate reporting standards for formats and climate topics that resonate with different stakeholders (e.g., EU Corporate Sustainability Reporting Directive (CSRD), Task Force on Climate-related Financial Disclosures (TCFD), International Sustainability Standards Board (ISSB) IFRS Sustainability Disclosure Standards, CDP (formerly the Carbon Disclosure Project), Global Reporting Initiative (GRI), Sustainability Accounting Standards Board (SASB), and B Corp (Air and Climate sections which focus on emissions) might be a helpful resource on climate reporting for small companies.

2.17 MANAGEMENT REVIEW AND CONTINUAL IMPROVEMENT

Background:

Continual improvement – comprising management reviews and performance monitoring – is an ongoing process of improving an organization and its products, services, and processes. A system of management reviews can be used to assess effectiveness and progress toward sustainable forestry objectives, including those established by forest certification. Annual reviews identify the changes needed to adjust management practices to reduce adverse impacts and achieve forest landowner objectives.

Climate Change and Continual Improvement

Climate change does not directly affect continual improvement processes. Yet, new climate-related information, technologies, and other external factors may influence management objectives and must be readily assessed and integrated with constant improvement. The volume of climate research for temperate forests has rapidly increased over the last ten years, changing our view of managed forests from being predictable under management to being far more uncertain due to climate change. Climate change will likely impact forest composition and productivity, but uncertainty in the long-term rate and intensity of change is becoming more apparent, making contemporary management decisions more challenging. New climate science and technologies for measuring forests and harvesting trees that increase efficiency and utilization and reduce greenhouse gas (GHG) emissions are improving how forests are managed. Continual improvement can leverage these emerging trends and new technologies to improve operational processes, attain objectives, and set new sub-objectives for achieving climate-smart forestry.

External factors such as changes in policy, forest certification (e.g., **SFI Objective 9**), markets for climate-smart products (e.g., pellets, mass timber, and other products with environmental product declarations), different supply chain pressures (e.g., EU carbon tariffs), and investor requirements are also affecting the management process and objective setting in forestry. For example, carbon programs are in flux, but carbon prices are increasing. This is affecting revenue opportunities and forest management decisions. If landowners elect to incorporate climate-smart forestry objectives into their overall management goals, these goals must be integrated into their continual improvement processes.

In the next two decades, the uncertainty posed by the extensive range of climate change projections will affect goal setting and performance monitoring. Landowners are inventorying their carbon and weighing the benefits of balancing carbon and wood fiber production. Objective setting is often based on performance criteria of maximizing or optimizing wood fiber yields and net present value or heuristic techniques (rules of thumb).

The uncertainty of future forest conditions created by climate change may require new methods for setting objectives and reviewing management performance. For example, an operational goal might be to minimize the risk of failing to achieve an outcome (e.g., wood fiber production or revenue goal). This can be done by applying "regret and satisfying" methodologies. The regret methodology establishes objectives to achieve the best performance under the most unfavorable climate change scenario to minimize the likelihood of regrets. The satisfying methodology sets goals that can be met under the most significant number of climate change scenarios to maximize the likelihood of achieving an outcome. These and other emerging methods for setting objectives may require changes to performance reviews and different overall evaluation criteria.

Climate-Smart Considerations

- *Scope:* Changing external factors (e.g., climate science and technology, policy, forest certification, markets, and investor trends) may require a review and realignment of company objectives related to climate-smart forestry and corresponding changes in planning and operations to information gathering, management reviews, and performance monitoring.
- *Uncertainty:* Most external factors (e.g., policy, markets, and investor trends) that press for climate objectives are influenced by political and business cycles and environmental policy life cycles that are unpredictable beyond five years and can reverse. Business sector and investor concerns about physical impacts and transition risks associated with climate change have increased over the last decade. Significant, unpredictable extreme events related to climate change (e.g., 2011 Tropical Storm Irene in Vermont, 2023 Halifax Wildfire in Nova Scotia) may result in short-lived climate programs at the state or provincial level. New requirements for forest certification for climate-smart forestry might be stable or increasing.
- *Scale:* Compared to large forestland managers, smaller commercial forestland managers may face less pressure and have limited capacity to respond to external pressures. U.S. publicly traded companies, including wood-product retailers, may need to meet future U.S. SEC climate change disclosure requirements on risk mitigation, GHG emissions, climate-related targets and goals, and transition plans. Companies that are sources for European supply chains may need to address requirements if emerging EU Carbon Tariffs are applied to wood products.

Climate-Smart Management Actions

Favorably Ranked Actions

- Have a process for keeping abreast of climate change science information related to forest management and forestry practices.
- Monitor impacts of climate-change-related risks and vulnerabilities and how they might affect the achievement of management objectives, including the future forest conditions through growth and yield modeling and validation.
- Monitor the effectiveness of implemented climate change adaptation and mitigation strategies.
- Include a summary of climate-smart forestry activities in the summary audit report prepared by the certification body for SFI.

Other Actions

- Monitor and evaluate the (1) environmental and social impacts of landowners' climate change adaptation and mitigation management strategies and (2) changes in long-term climate and weather, using a monitoring protocol or monitoring information from government agencies and available research.

Resources

Hallegatte, S., 2009. Strategies to adapt to an uncertain climate change. Global environmental change, 19(2), pp.240-247 *(academic, identifies several methods for managing climate uncertainty).*

Janowiak, M., K. Schmitt, D. Shannon, P. Leopold, L. Brandt, S. Handler, T. Ontl, C. Peterson, C. Swanston. 2022. A Quick Guide to Adaptation Planning for Natural Resource Professionals. Northern Institute of Applied Climate Science, and USDA Northern Forests Climate Hub *(a quick guide to understanding the basics of climate adaptation planning).*

Magnan, A.K., Schipper, E.L.F. and Duvat, V.K., 2020. Frontiers in climate change adaptation science: advancing guidelines to design adaptation pathways. Current Climate Change Reports, 6, pp.166-177 *(academic, identifies how two dichotomies [actions are either incremental or transformational, and they are either maladaptive or adaptive] limit designing context-specific adaptation pathways).*

Ontl, T.A. and others, Forest Management for Carbon Sequestration and Climate Adaptation, Journal of Forestry, Volume 118, Issue 1, January 2020, Pages 86–101, https://doi.org/10.1093/jofore/fvz062 *(academic but practical lists of adaptation and mitigation strategies/actions).*

Werners, S.E., Wise, R.M., Butler, J.R., Totin, E. and Vincent, K., 2021. Adaptation pathways: A review of approaches and a learning framework. Environmental Science & Policy, 116, pp.266-275 *(describes adaptation pathways to applying continual improvement given high levels of impact uncertainty, with natural resource management examples).*

Yousefpour, R. and Hanewinkel, M., 2016. Climate change and decision-making under uncertainty. Current Forestry Reports, 2, pp.143-149 *(discusses diversifying portfolios and robust decision-making approaches under climate change uncertainty. It is academic but short and reasonably practical).*

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Mina, M., Messier, C., Duveneck, M., Fortin, M.J. and Aquilué, N., 2021. Network analysis can guide resilience-based management in forest landscapes under global change. Ecological Applications, 31(1), p.e2221.

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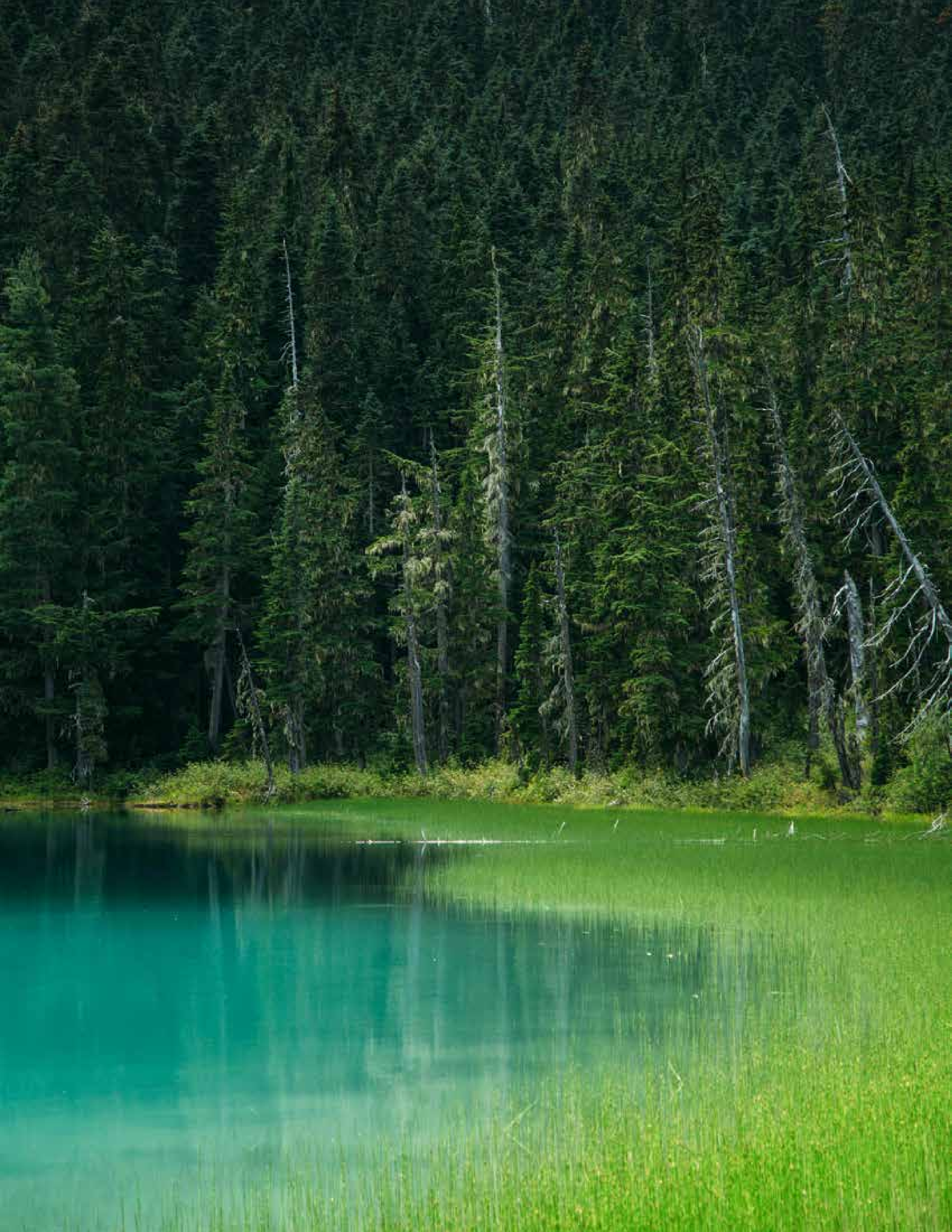

SECTION 3

CLIMATE CHANGE AND RISKS

ERIC WALSH AND ANDREW WHITMAN

3 | INTRODUCTION

This section evaluates the climate risks of greatest concern identified by forest managers and the literature. In a 2023 survey, forest managers in the Northeast were asked to rank the likelihood of the occurrence (Very Likely, Likely, Neutral, Unlikely, Very Unlikely) and the impact (Extreme, Major, Moderate, Minor, Insignificant) of climate change risks on forest ecosystems. Many of these same risks have been identified as important in other survey studies from the region.[1] This section presents a snapshot of the projected impacts of those risks and potential forest management actions filtered through a climate-smart forestry (CSF) approach. It is not intended to be comprehensive and cover all risks. Instead, the more significant risks are used to demonstrate the application of CSF to risk assessment and management.

The format for each risk is the following:

- *Forest Manager Assessment:* The occurrence likelihood and impact reported by managers in the most recent climate-smart forestry survey.
- *Synopsis:* A summary overview of the projected impact and potential climate-smart forestry actions to take in response.
- *Impacted Forest Type:* The forest types most impacted (when applicable).
- *Projections:* The projected occurrence and impact of the risk under climate change.
- *Climate-Smart Actions:* The potential actions to address the risk assessed through a climate-smart forestry approach.

3.1 PESTS AND PATHOGENS

Forest Manager Assessment: *Likely* to occur, *Major* impact.

The impact of pests and pathogens and the actions that must be taken in response to them will vary considerably. Generally, new pests and pathogens are projected to emerge and established ones are expected to become more frequent as temperatures increase, especially in winter. (The exception is the eastern spruce budworm, which may decline due to warming.) Compounding these effects will be interactions between other stressors, like drought and outbreaks of less impactful pests and pathogens. Precise predictions of pest and pathogen distributions and impacts are limited by the uncertainty of dispersal, infection, and transmission mechanisms.[2] The National Insect and Disease Risk Map[3] is valuable for spatially explicit, short-term pest and pathogen at-risk information. These data and host tree distribution maps can provide a baseline assessment for at-risk stands.[4]

An effective approach is to view impacts and solutions through a "whole ecosystem" lens.[5] Decisions can have unforeseen effects if not considered in the context of the whole forest ecosystem. For example, while certain climatic conditions may lead to increased tree growth, the same conditions can also create a favorable environment for pests and pathogens that can ultimately suppress growth.[6] In addition, there is evidence that management actively engaged in preventing pest outbreaks can result in forest conditions that lead to increased risk and more frequent outbreaks of pests,[8] such as when the fire suppression throughout the 20th century led to an increased risk of wildfires.[7] The "whole forest ecosystem" approach considers how the impacts of different decisions effect each other and seeks to optimize multiple outcomes – for example, optimizing the mitigation of drought, pests, and pathogens without compromising growth.

3.1.1 Southern Pine Beetle (SPB)

Synopsis:

- SPB infestations are projected to expand northward as average winter temperatures increase.
- The climate-smart approach will require balancing tradeoffs between optimizing timber, carbon, and other ecosystem benefits and adapting stands to persistent infestation.

Impacted Forest Types:

- Central Hardwood — pines
- Pitch pine/Scrub oak

Projections: Infestation frequency and severity are projected to rise as the pest species' range expands north under warming winter temperatures.[9] Rising winter temperatures and past winter and spring moisture deficiencies both stimulate infestations.[10,11] As average winter temperatures increase, the temperature threshold necessary to limit the pest population (3°F (-16°C12)) will occur less frequently. By 2050, 78% of previously unaffected pitch pine habitats will be suitable climate for SPB.[13]

Climate-Smart: There are three silvicultural management approaches for SPB infestation: no management, preventative thinning, and direct control or suppression silviculture (e.g., cut and leave, and cut and remove). In southern pine ecosystems, suppression silviculture helps reduce additional infestations.[10,14] Preventative thinning is recommended,[14] though not as a regular practice,[15] and it is not always found to minimize infestations in the regions of range expansion.[10]

Traditionally, silvicultural approaches were based on the value of the timber at risk. However, accounting for at-risk carbon values would lead to different management decisions. A study from the New Jersey Pine Barrens[15] found the following tradeoffs between carbon and timber values based on no-management, preventative-thinning, and direct-control interventions:

- Preventative thinning reduces infestation risk to its lowest rate among the three interventions.
- Preventative thinning results in the lowest retained carbon density on the landscape.
- No-management and direct-control (both cut-and-leave and cut-and-remove) approaches result in the most significant

amount of retained carbon on the landscape.
- o A cut-and-remove approach can result in unintended consequences by increasing the risk of wind disturbance to the remaining trees.16

- Even though landscape carbon retention is maximized in non-thinning interventions, other ecosystem benefits and dynamics may be impacted by the increased tree mortality; these include water quality and quantity, the continued persistence of SPB, suitability for recreational use, and wildfire risk.

Stand density reduction has a concurrent carbon cost which can be transferred to the social carbon pool, offsetting carbon losses that would otherwise be transferred to the atmosphere more quickly. Forest ecosystem carbon reduction is a short-term tradeoff to increase the long-term resiliency of a stand.

Monitoring is crucial to any climate-smart forestry strategy. It is possible to detect the severity of SPB infestation early by using remote sensing products and monitoring winter dew point temperatures that dip below 0°C.[11]

3.1.2 Hemlock Woolly Adelgid (HWA)

Synopsis:

- As winter temperatures increase due to climate change, HWA will likely track northward, though projections are less certain for the northern and eastern extents of its range.
- Future extreme drought events may enhance HWA-induced mortality.
- Though projections indicate that HWA-induced forest composition shifts (like those that come with no-management intervention) have minimal impacts on carbon dynamics, observations from southern New England do not align with these expected trends.
- New technologies are becoming available to refine detection and enhance monitoring efforts.

Impacted Forest Types:

- Low-elevation spruce-fir
- Lowland and Riparian Hardwoods
- Transition Hardwood

Projections: HWA infestation is limited by winter temperatures, with a combination of winter (DJF) average daily minimums, average daily temperatures, and minimum temperature duration all contributing to high adelgid mortality.[17] As winter temperatures increase, HWA may increase or more easily remain established in stands.[17,18] Expansion is expected to cease at locations with a winter average daily temperature of –5°C.[17] However, at the northern and eastern edge of the hemlock range, projections tend to underpredict the spread of HWA (Fig 2).[18] Though the reasons are uncertain,[18] HWA is adapting to colder environments, facilitating a northward expansion,[19] which may contribute to a mismatch between models and observations. HWA-driven declines in the hemlock overstory, such as those observed in southern New England in the last several decades, will likely occur in New York, northern New England, and

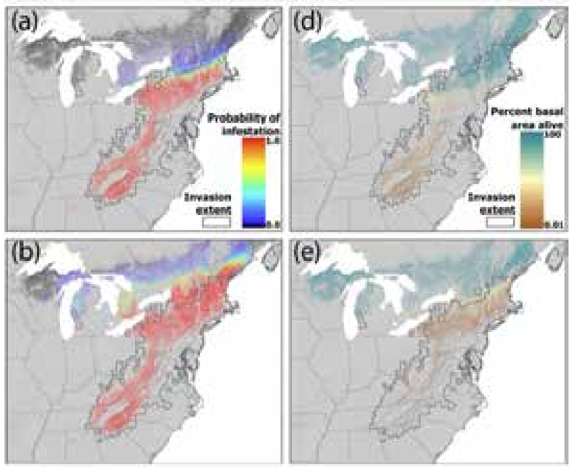

Figure 2. The modeled 2015 (a) and 2030 (b) hemlock woolly adelgid infestation probability and corresponding estimated hemlock basal area lost (d, e) based on the average of different climate scenarios. The 2017 observed infestation extent is noted by a grey line. Image reproduced from Ellison *et al*. 2018.[18]

Southern Canada over the next 20 years.[18] There is some indication that extreme precipitation periods result in declines in HWA via fungal attack,[20] which has implications for infestation under future increases in precipitation.[21]

Climate-Smart: Resiliency and adaptation begin with prevention. Emilson and Stasny[22] developed a decision support framework that identifies the following actions as best practice preventative measures: education, monitoring, prioritization of high-risk stands and activities, and overall evaluation of prevention protocols. Many monitoring and reporting efforts are occurring across the Northeast and Canada, with no single method providing effective low-density detection results.[22] New remote sensing and LIDAR technology that detects structural differences within the canopy layers provide possible advancements in early detection and disturbance monitoring of HWA.[23] Additionally, eDNA detection appears more sensitive and cost-effective than conventional detection methods.[24,25]

Once the pest is established, HWA management activities are complex and based on three options: *eradication, control,* and *do-nothing*, all with potential carbon, economic, and biodiversity outcomes.

HWA eradication is an intensive management approach involving harvest-based silvicultural management (e.g., thinning, salvage logging, total stand harvesting), which will likely yield limited results. Evidence of infestation control through stand thinning is limited.[22] There is evidence that increasing light penetration reduces HWA infestation and improves tree carbon balance; however, those results were associated with seedlings.[26] Individual tree vigor associated with HWA infestation is improved through thinning,[27] which has implications for potential approaches to other disturbances. Hemlock is a drought-intolerant species, and HWA infestation compounds drought-induced water stress because it leads to the loss of fine root mass,[28] diminishing the ability of the tree to take up water.[29,30] Though thinning is a management tool for drought, the effect on interactive disturbances and carbon consequences is unclear. Without climate change, a do-nothing approach results in a slow transition from hemlock to early-successional hardwood species (e.g., yellow birch), which is projected to have marginal impacts (2%–5%) on total ecosystem carbon over several centuries post infestation31. However, observations in southern New England indicate that the decline in the oldest hemlock stands is occurring more rapidly than expected, causing some forests to shift from carbon sinks to carbon sources.[18]

Pre-salvage harvest, or the harvest of trees before they are damaged, is a common HWA management action with forest carbon implications. Projected near-term (<35 years) carbon storage and continued sequestration were more significant in HWA-infested stands not subjected to pre-salvage management, because infestation shifts carbon storage to fallen trees and new saplings. However, pre-salvage management can maximize timber revenue with a tradeoff in forest carbon storage and sequestration.[32] The carbon balance tradeoffs of transferring pre-salvage harvested biomass from the forest ecosystem versus waiting for longer-lived wood products are unclear. Biodiversity, however, is impacted; the composition of the local and regional bird population shifts with the loss of hemlock structural canopy.[33,34]

3.1.3 White Pine Needle Damage

Synopsis:

- White pine needle damage is caused by a fungal complex of at least four species and is likely a result of those fungi migrating north because of climate change.
- The overall risk to eastern white pine posed by white pine needle damage is complex because of multiple interacting effects of climate change on the species.
- Continued sampling is vital for early detection and adaptation, especially by ground-based efforts.
- Stand density reduction, which is primarily focused on small-diameter trees, is a viable adaptation action; however, the carbon implications are uncertain compared to no management intervention.

Impacted Forest Types: Transition Hardwood

Projections: White pine needle damage (WPND), widely distributed across the Northeastern states,[4] is caused by a fungal complex of at least four species. Some have only recently been associated with the region; a likely result of climate change-induced northern migration.[4,35] High-risk areas include stands with >50% eastern white pine (basal area) and a four-state region (ME, NH, VT, and MA) with a continuous distribution of eastern white pine acting as a conduit for disease spread.[4]

The impact of climate change on the risk to eastern white pine is complex. Studies show that rising temperatures and increased spring rain have positively impacted the growth of eastern white pine.[36] However, some of these same changes are strongly related to defoliation events. Increased May–July total precipitation, warmer winters, and cooler springs precede defoliation events in the following years.[4] Specifically, rain events with consecutive days of high humidity are related to the dispersal of spores from infected trees.[37] An increase in rain and winter temperatures could enhance the spread of damaging fungus.[21,38] However, relative humidity is projected to decline (relative to historic climate) during spring by the end of the century.[39]

WPND could interact with the projected eastern white pine range shift, which is predicted to spread northward while reducing elsewhere.[40] The decline of eastern white pine would be sped up through the impacts of climate change on nutrient cycling, photosynthesis, and tree growth,[41,42] ultimately affecting ecosystem function and timber production.[43]

Other pathogens like white pine blister rust, root and butt rot fungus, and canker pathogens are also favored by climate shifts in the Northeast and affect trees impacted by WPND.[43]

Climate-Smart: Continued sampling, especially by ground-based efforts,[4] is key for the monitoring and early detection of pests and pathogens. It is also crucial to monitor trees that are at higher risk due to their smaller diameter at breast height (DBH) and reduced growth rates, because these will likely experience interactive effects from drought-induced stress[44] and WPND.[41,45] Less intensive detection methods using acoustic sampling[46] and remote sensing have been reported. Remote sensing models appear to work for higher severity defoliation events; however, these detection methods are less viable at lower severities.[47]

Several location-specific data sets can facilitate targeted silvicultural planning to address WPND. Range and projection maps of eastern white pine,[40] coupled with contemporary host layer risk maps,[4] can inform the balance of short and long-term management actions.

Stand density reduction that is primarily focused on removing small-diameter trees is a viable adaptation action. WPND severity among infected trees declines after the application of pre-commercial thinning.[45] The increased distance between crowns allows light to penetrate the canopy, likely limiting pathogen dispersal by lowering the humidity.[37] Density reduction measures have other co-benefits like drought adaptation (see Drought section) and improving lumber grading and financial returns by minimizing pathogen damage to wood.[48] Stand density reduction has a carbon cost which can be transferred to the social carbon pool, offsetting carbon losses that would otherwise be transferred to the atmosphere more quickly. Forest ecosystem carbon reduction is a short-term tradeoff to increase the long-term resiliency of a stand. The balance between removing carbon to minimize pathogen impact and retaining carbon at the cost of increased infestation is unknown. Consequently, the long-term carbon trajectories based on management actions to address WPND are uncertain.

3.2 DROUGHT

Forest Manager Assessment: *Likely* to occur, *Major* impact (as an interacting factor with other stresses, like pests and pathogens, causing tree mortality).

Synopsis:

- Forests in the Northeast are generally characterized as *balanced* (i.e., dominated by a mix of drought-tolerant and drought-intolerant species) or *somewhat intolerant* to drought.
- Drought-related mortality is typically driven by indirect (e.g., insects, fungal pathogens, and soil nutrient changes) rather than direct (e.g., soil moisture deficit) factors
- Stand density reduction, an often-cited method for drought mitigation, has mixed results for reducing tree loss directly due to drought. However, it is likely beneficial to reduce indirect drought-induced stress.

Impacted Forest Types: Northeast region

Projections: Drought and soil moisture regimes are critical controlling factors in the distribution and survival of plants[49] and the primary drivers of ecosystem change. Drought directly or indirectly influences vegetation growth, regeneration, nutrient cycling, pest and pathogen outbreaks, and wildfire dynamics.[50] Drought impacts forest ecosystems by limiting the availability of moisture in soil, which is determined by the timing of precipitation, temperature, and evaporation.[51] As a result, drought effects on forest ecosystems are complex and often vary across different severities, ranging from flash to long-term drought, and spatial scales, ranging from stands to regions.

Paradoxically, while the Northeast has become wetter through the 20th century and drought frequency has declined, drought intensity and duration have not changed[52] even with increased precipitation. Annual mean precipitation is projected to increase through the 21st century.[53] However, drought risk is not likely to decline because warming temperatures will increase evapotranspiration (the total water loss to the atmosphere from a given land area). The impact of these two trends on soil moisture levels is uncertain.[53] Projections for drought risk are uncertain under climate change, and the risk of extreme drought events may increase slightly. If drought frequency and intensity do not change, the death of trees due to drought might increase when drought is accompanied by extreme heat events.

Climate-Smart: Tree species' drought classification is typically based on their *sensitivity* (i.e., the adaptive capacity to avoid dehydration) and *tolerance* (i.e., the capacity to survive moisture stress). Forests in the Northeast range from *balanced* in response to drought (i.e., dominated by a mix of drought-tolerant and drought-intolerant species) or *somewhat intolerant* to drought.[54] This range in part reflects how many Eastern forests have shifted from oak-dominated to the wetter, maple-dominated forests in southern areas of the region.[55] Overall, drought-induced mortality in Northeast forests has been infrequent[56] because of the increasing precipitation trend in the 20th century.[57] Drought-related mortality is more likely due to drought interacting with other stress-inducing factors like pests, fungal pathogens, and changes in soil nutrients.[58]

More commonly, drought in the Northeast region can reduce tree growth,[59] an impact which is influenced by stand density.[60] Thinning that changes stand composition and reduces stem density can be used to reduce drought vulnerability or increase the capacity of stands to adapt to drought. Additionally, forest treatments that reduce indirect impacts such as pest and pathogen outbreaks can increase the adaptive capacity of trees to drought and reduce direct drought impacts (e.g., growth declines, mortality).

Stand density reduction is often suggested as a management action to increase the adaptive capacity of stands to drought. A 2022 research synthesis[61] indicates that lowering stand density does not always result in the adaptive growth responses that achieve forest resistance, resiliency, and recovery. The key findings for this synthesis are the following:

- Tree response to drought is species-specific.
- Stand density does not always correlate with resistance to drought. However, if there is an association, dense stands tend to be less drought resistant and respond with reduced growth.
- Overall stand resilience and recovery (i.e., the capacity for growth to rebound to pre-disturbance levels) is typically reduced for up to four years post-drought,[62] and shows no relationship with stand density.
- Variable responses were most likely to be observed when drought intensity was low or moderate. At increased drought intensity, all stands were affected regardless of density – in other words, thinned stands were not resistant. Recent studies indicate this may not be true of all forest ecosystems.[63]
- The effect of thinning on drought resilience declines over time if density management is not maintained.[64]

Research on the thinning of stands to manipulate stand carbon dynamics has had mixed results. Thinning affects individual tree production with little effect on stand or long-term production,[65] and this may create a persistent carbon debt.[66] Drought tends to have less impact on ecosystem carbon balance in the more humid, eastern forest types.[67] However, drought-induced stress can increase the susceptibility of stands to pathogen outbreaks. This can reduce ecosystem carbon such that a forest shifts from being a carbon sink to a carbon source.[67] Thinning, as a management response to mitigate indirect drought impacts like pathogen outbreaks, may be useful for maintaining long-term ecosystem carbon.

Stand age and species diversity is an adaptive management approach for drought. Increasing species diversity using more drought-tolerant species may increase stand resistance and resilience by distributing risk.[67,68] In addition, thinning is best focused on removing small trees that have reduced growth rates, as these are at greater risk from drought.[44]

Landscape and infrastructure design can increase the adaptive capacity of a forest.[69] Redesigning and remediating roads can increase moisture infiltration and reduce runoff, allowing for greater water retention within the landscape,[70] tree productivity,[70] and net carbon gains.[71] Combining thinning with managing for stand age and species diversity, planting adapted species, and managing roads for water systems can holistically and robustly reduce drought risk. This climate-smart approach can increase the adaptive capacity of northeastern forests to drought risk and mitigate drought's impacts on forest carbon and production.

Carbon losses from drought and heat stress can be addressed by also considering carbon storage in the wood product supply chain. Forest ecosystems less vulnerable to drought can be managed to focus on increasing carbon sequestration to offset emissions within the supply chain.[72] More vulnerable forests can be a focus of adaptation actions to maintain carbon stocks, and carbon that is removed through adaptive measures such as thinning is transferred into harvested wood products (HWPs) with long-term carbon storage potential.[72]

3.3 EXTREME WEATHER EVENTS (ACUTE)

Forest Manager Assessment: *Likely* to occur, *Major* impact. Throughout the 20th century, the Northeast region experienced a gradual increase in average annual temperature and precipitation.[73,74] There has been a noted increase in warming events, such as warm nights and summer days, accompanied by a decrease in cold spells and frost days.[75] Extreme precipitation events have also been increasing, with four times as many extreme events (>150 mm/day) during 1997–2014 compared to 1979–1996.[76] However, this precipitation trend does not appear to mitigate drought. The hot extremes in the Northeast have been increasingly correlated with drier conditions.[73,77]

3.3.1 Precipitation

Synopsis: Extreme precipitation in forest ecosystems can increase flooding, erosion, and nitrate leaching, impacting surface and groundwater resources, as well as infrastructure.[78–80] Managing for increased soil water infiltration and retention can offset some of these impacts. Such management depends on altering the forest ecosystem's composition, structure, and road infrastructure. A robust adaptive management approach integrates hydrologic and forest ecosystem models to simultaneously assess impacts.

Impacted Forest Types: Northeast region

Projections: Increasing precipitation extremes are projected to continue through the 21st century.[74,81,82] In the coming years, the fall season (September through November) is expected to experience a significant precipitation increase compared to other seasons.[81]

The impacts of extreme precipitation events are various. They can increase flooding, stream flow, and soil erosion,[79,83] with Vermont particularly vulnerable to erosion.[84] This can result in tree mortality, carbon losses, and increased maintenance/operational costs.[85] However, these events do not appear to affect regeneration, meaning they do not either offset drought-induced mortality or increase mortality due to the oversaturation of soil.[86] Increased evapotranspiration due to rising temperatures may enhance northeastern forest ecosystems' resilience to increased runoff from precipitation.[87] There is also evidence that extreme precipitation events cause a decline in mycorrhizal fungi, which are essential components of carbon and nitrogen cycling.[88]

Climate-Smart: The flow of water from a drainage basin is more affected by forest composition than climate-change-induced precipitation changes (e.g., Northeastern eastern hemlock vs. American beech cover).[89] In addition, the interaction between hurricane-induced precipitation and forest composition can have an enhanced impact on basin flooding.[89] The composition and structures of forest species interact with topography to have lasting impacts on stream flows, especially during peak flow.[90]

Adaptive forest management actions can increase the capacity of soil to absorb excessive precipitation and alter stream flows. Such actions can include modifying forest cover area, dominant species composition (leading to greater evapotranspiration rates[91]), or functional types (e.g., deciduous to conifer conversion).[89,90] However, these management approaches require careful consideration, planning, and the integration of the forest ecosystem with hydrologic models, because basin stream flows will also be altered and impacted.[90,92]

Extreme precipitation events can significantly impact operational infrastructure and capacity, like culverts and access. Advanced GIS modeling can provide new risk-assessment techniques to evaluate the vulnerability of culverts and erosion hazards.[80]

3.3.2 Temperature

Synopsis: Extreme heat events are often coupled with drought conditions.[93] However, even when independent of drought, these events can still impact forest productivity.

Impacted Forest Types: All

Projections: The Northeast is projected to experience more warm extreme temperatures, less cold extreme temperatures, and increases in heat waves in the latter half of the century.[82] Contemporary northeastern heatwaves have reduced forest carbon sequestration rates and tree biomass, which will continue as these heatwaves increase in frequency under future climate change.[87] Even short-term heatwaves in the early part of the growing season can reduce within-year productivity.[94] However, because wet conditions have typically preceded heatwaves in the Northeast , the region is considered more resilient than other regions because soil moisture availability is less impacted by warming trends.[87]

Climate-Smart: Tree retention is a strategy to provide shade and reduce heat stress for seedlings. Even one tree can mediate microclimate air and soil temperature in a stand.[95]

Temperature extremes can uniquely impact occupational hazards, because heat waves present an emerging risk. In regions that experience consistent and prolonged heatwaves, occupational injury claims increase significantly with heatwave events.[96] Collaborative actions between employers and workers can reduce heat risk. Improvements include accessible hydration, better clothing that maximizes cooling, increased acclimation, and access to shade.[97]

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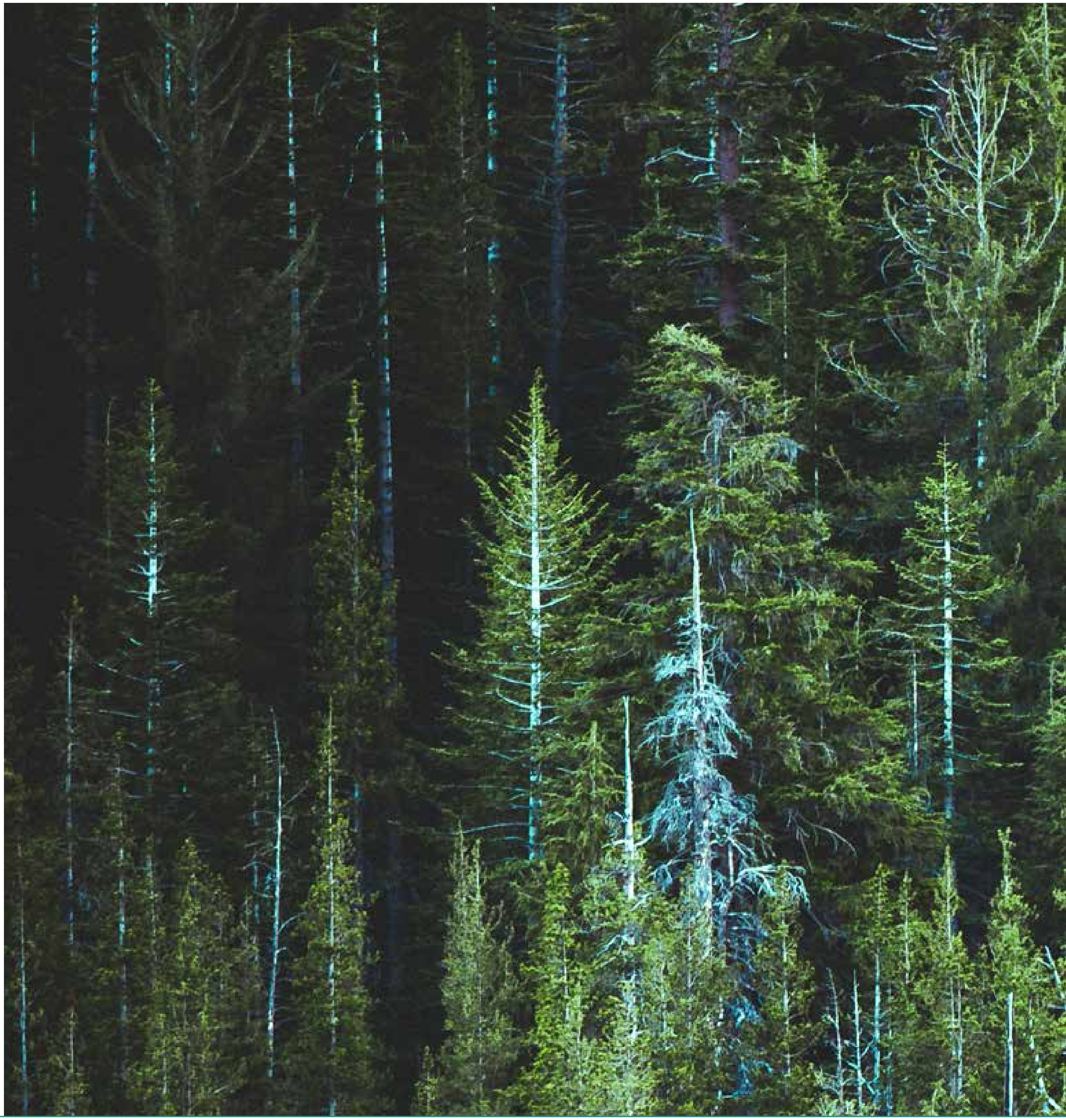

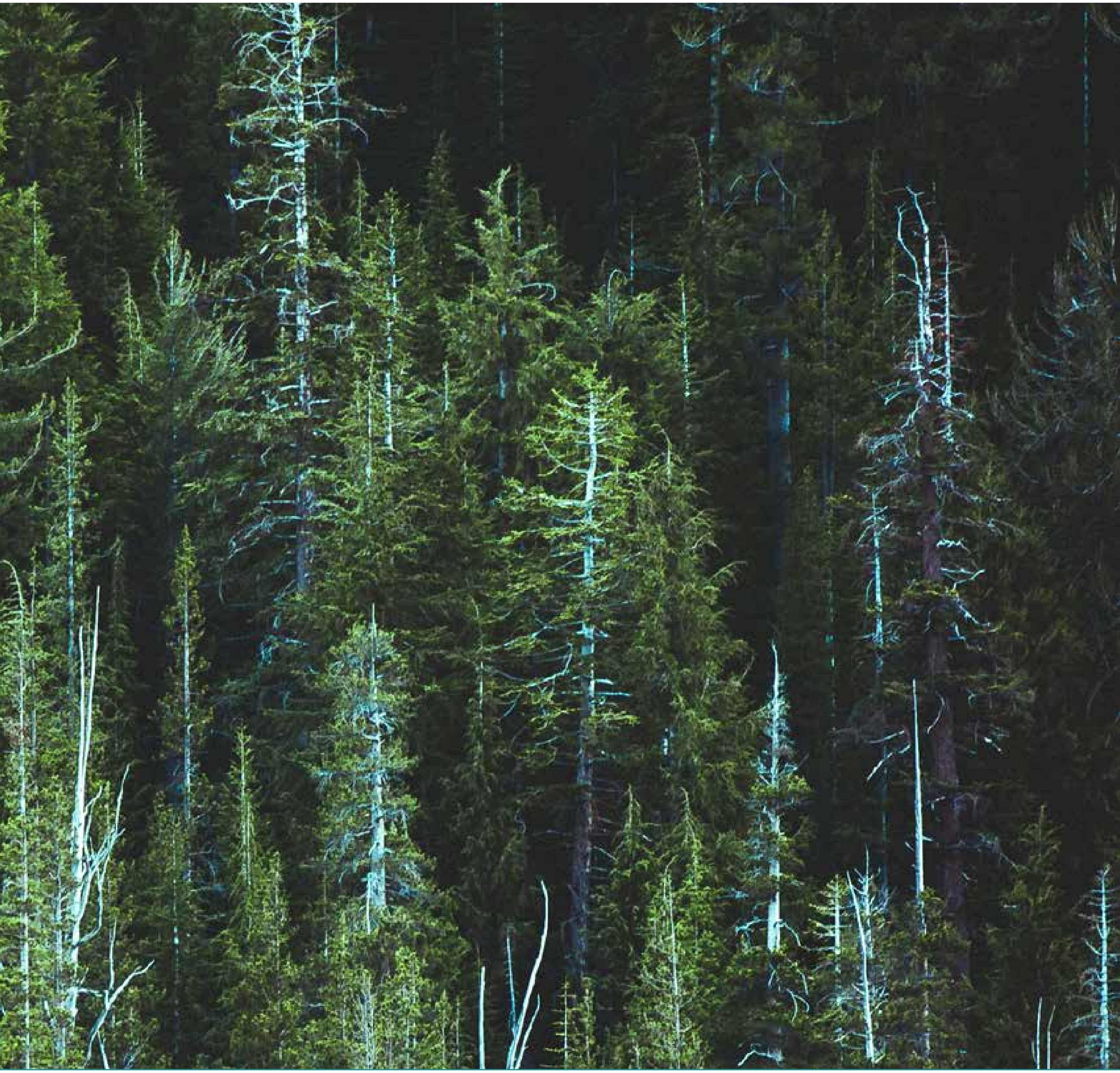

SECTION 4

CLIMATE CHANGE: MANAGEMENT ACTIONS

ERIC WALSH AND ANDREW WHITMAN

4 | INTRODUCTION

This section reviews the management and silvicultural practices/ actions frequently noted in previous sections.
In a 2023 survey, forest managers in the Northeast were surveyed to provide feedback for different climate-smart forestry practices. Specifically, for each practice, they were asked to rate the current frequency of its use, its effectiveness at mitigating climate impacts, and their willingness to recommend a practice to peers (for results and explanation, see Appendix B). Responses were ranked for *Application* (Very Likely, Likely, Neutral, Unlikely, Very Unlikely), *Effectiveness* (Substantial, Somewhat, None), and *Recommendation* (Excellent, Very Good, Good, Fair, Poor).

The results of this survey are presented at the beginning of the following sections that describe key climate-smart practices. This is followed by an operational assessment of climate-smart practice – particularly its potential to adapt to and mitigate the results of climate change – as found in scientific literature. Every management action creates tradeoffs between long- and short-term adaptation and mitigation goals to manage.[1] The intended outcomes and anticipated tradeoffs must be considered within the climate-smart forestry (CSF) framework for management actions.

4.1 SILVICULTURE

4.1.1 Thinning/Density Management

Forest Manager Assessment: Application: *Somewhat*; Effectiveness: *Very Good*; Recommend: *Likely*

Climate-Smart: Thinning/density management is a common silvicultural tool for limiting the impacts of low soil moisture levels, mitigating biological disturbances, and encouraging the regeneration of species maladapted to climate change.[2] Forests maintained at intermediate[i] stand densities appear to be best for below- and aboveground carbon storage.[3] One long-term strategy for density reduction is using light, partial harvests at regular intervals to produce a well-spaced, unevenly-aged stand. This treatment can reduce the impacts of pest and pathogen outbreaks and drought, improving the forests' resilience to disturbance through carbon storage.[3] The approach depends on gradually replacing larger, harvested trees with smaller trees via natural regeneration. Post-partial-harvest sapling growth and mortality can vary greatly across different species in the Northeast and can include mortality from logging damage and a delayed growth response.[4]

Partial harvest generally may have less impact on soil carbon levels than clear-cut harvesting; however, results are mixed across forest types.[5,6] Under partial harvest regimes, soil disturbance is assumed to be minimized, and the resulting fungal community dynamics may favor less decomposition and loss of carbon from the soil, especially in the forest floor organic layer.[3] CSF plans with specific carbon goals would benefit from evaluating the impacts of differing harvest intensities on belowground carbon dynamics.

Secondary effects from thinning can have unintended consequences on ecosystem carbon dynamics. Windthrow – the uprooting of trees by wind – is the predominant natural disturbance in the Northeast[7] and is exacerbated by thinning[8,9] because of the increased exposure of residual trees to wind without adequate stem taper or adaptive root or crown structural development.[10] Ecosystem carbon losses can be enhanced by windthrow[11,12] and compounded through salvage logging. As a result, the fate of the salvaged wood carbon determines the overall forest sector carbon balance, whether it is used in long-term harvested wood products (HWPs) like furniture or in items that are thrown away.[13] Maintaining awareness and plans for the secondary effects of thinning on carbon dynamics is strategic for CSF carbon accounting.

As demonstrated in mixed wood balsam fir-birch stands, it is possible to maintain natural composition diversity with precommercial thinning while increasing growth.[14] However, precommercial thinning can be cost-prohibitive, especially for risk reduction purposes, because there is not a direct financial benefit to this risk-reduction practice.[15] Even with commercial thinning, financial benefits may not accrue for up to two decades.[16] Cost-sharing incentive programs are one possible solution and may reduce the externalization of risk, such as your neighbors' inactions raising the risk of a threat to your land.[15]

Based on expected below- and aboveground mechanistic relationships within forest ecosystems, intermediate stand density is appropriate for balancing carbon, resiliency, and climate change impacts.[3] However, the optimal stand density, structure, and compositional mix that increases these desired outcomes is a significant research opportunity at local and regional scales.[3] There is insufficient evidence to determine the optimal stand density for localized conditions when balancing climate-smart forestry outcomes.

4.1.2 Compositional and Structural Diversity

Forest Manager Assessment: Application: *Somewhat*; Effectiveness: *Very Good*; Recommend: *Likely*

Climate-Smart: Forests with increasing species richness, composition, and functional diversity are more likely to be resilient to climate change[17–20] and deliver consistent ecosystem service benefits than stands with lower levels of these attributes.[21] This is especially true for forest ecosystems projected to decline in productivity due to climate change.[17] Stands with species and genetic diversity have a higher level of resistance to and recovery potential from disturbance events and overall shifts in environmental conditions.[22,23] For example, tree species diversity

[i] Intermediate is a qualitative term and should be interpreted as relative to the stands under management.

can improve growth resiliency during drought conditions,[ii,24] since it distributes risk across species.[25]

Greater tree species diversity is generally associated with greater levels of carbon in forest soil and greater productivity.[20,26–28] There can be a tradeoff between increasing the levels of carbon stocks and the capacity of a forest to adapt to change: a decline in climate change mitigation. As a result, implementing silvicultural systems, such as thinning, that balance adaptation and mitigation is preferrable.[18] Shelterwood systems, those that plant seedlings under the canopy of genetically diverse seed trees, balance these tradeoffs if climate change does not adversely impact regeneration. Coupling shelterwood treatments with reserves can meet both biodiversity and adaptive objectives, though this can reduce revenue. Cumulative productivity, though, is expected to increase over time in very diverse stands as multiple species exploit the available niche space.[28] Even so, productivity and carbon stocks may be at greater risk of decline under future climate change and disturbance – diverse stands may fare better, given the potential risks.[19,20]

At the landscape scale, diversity of tree species and stand characteristics can increase the resiliency of a forest.[29] Pest outbreak cycles can be dampened within landscapes that are maintained for structural diversity,[30] and broad-scale outbreaks can be avoided with increased forest diversity at the landscape scale.[31] In addition, diverse forested landscapes with climate-adapted trees reduce risk without compromising regular harvest production.[32]

Stand diversity that will thrive in future climate conditions can be increased through assisted migration,[33] because natural migration may lag behind the comparatively rapid dynamics of climate change.[34] The productivity of planting new tree species is nuanced and highly dependent on the future conditions of each location.[27] In the eastern U.S., a comprehensive dataset on the potential suitability of tree habitats under climate change can assist managers in determining compositional shifts via natural regeneration and assisted migration,[34] yet further work is needed to align species with site-specific conditions. Planting climatically suitable species can enhance ecosystem service benefits (ESB). However, the costs must be balanced with marginal increases in ESB.[21]

4.1.3 Lengthened Harvest Intervals

Forest Manager Assessment: Application: *Somewhat*; Effectiveness: *Very Good*; Recommend: *Likely*

Climate-Smart: Increasing the harvest interval length – waiting longer to harvest wood from a stand or forest – can improve climate mitigation. The approach increases[iii] the standing carbon stock[35] and decreases atmospheric CO_2, which has been shown to have a climate cooling effect in systems outside of the Northeast.[36] The economic incentives for forests to provide climate regulation services through carbon sequestration and storage can lead to longer rotations.[37,38] By extending stand rotation, carbon or harvested timber can be increased with minimal net management costs.[39–41] However, increased rotation decreases adaptive management practices like selecting for better, climate change-adapted tree species.[41] Increased rotations may reduce carbon storage in harvested wood product (HWP) if the benefits of product substitution (e.g., using wood instead of steel studs and concrete) are delayed;[35] however, additional life cycle analyses are necessary to quantify this effect fully.

Extended rotation may also improve structural attributes that provide ecological benefits like those of mature and old-growth forests,[42] especially if salvage logging and additional thinning are restricted.[41] The biodiversity implications will depend on the target species; for example, deer and moose benefit from the forage availability of young stands, which would diminish under increased rotation.[41] Extended rotations can increase the vulnerability of standing wood to disturbance events due to exposure.[40] It can also result in saw timber log diameters exceeding the optimal size. The risk of economic loss by extending rotations under conditions when trees are at greater risk of damage is offset by keeping carbon on the landscape – even when damage occurs, carbon stocks are more economical than transitioning to shorter rotations.[43]

4.1.4 Shortened Harvest Rotation (*also known as* Deferred Harvest)

Forest Manager Assessment: Application: *Somewhat*; Effectiveness: *Good*; Recommend: *Neutral*

Climate-Smart: Decreasing stand rotation and harvesting more frequently is intended to increase forests' resistance to disturbance events and has applications for adapting to climate change. Conventionally, reduced rotation can reduce the impacts of disturbances such as bark beetle and windthrow; however, climate change may diminish the efficacy of this approach.[44] Simulations have found that climate change increases the severity or frequency of disturbance events enough to decrease the resiliency gains from reduced rotation.[44] Even though stands are exposed to distrubance for less time, they are subjected to greater severity and frequency compared to historically normal disturbance events.

Additionally, the application of reduced rotations over long periods can reduce overall growing stock and primary productivity, resulting in a decreased use of large trees and less production of products that use older or larger wood.[45] Reduction in rotation length requires careful attention to maintaining forest productivity (e.g., annual increment) and market opportunities.

Reduced rotation is an economically viable adaptation option when the risk is primarily drought.[iv, 46] On the other hand, decreased rotation may increase the negative effects of

[ii] The response is not always associated with growth resiliency, but there is a lack of mechanistic understanding of the relationship between diversity and improved tree growth under drought.[24]

[iii] The increase at the stand level is related to the actual average changes from one rotation to the next; thus the effect is only for the initial change in rotation, and without subsequent increases, the average carbon stock will not change.[35]

harvesting on streams and water quality, which, if implemented at scale, could impact entire watersheds[41] Impacts associated with greater tree density and exposure to soils with low vegetation cover can be mitigated by applying existing water quality best management practices (BMPs). At scale, shortened rotation may produce a landscape that is not ecologically consistent with natural disturbance regimes, microclimates, and habitats[41] Decreasing stand rotation requires careful consideration of landscape connectivity to acheive biodiversity objectives.

4.2 MONITORING

Forest Manager Assessment: Application: *Somewhat*; Effectiveness: *Good*; Recommend: *Neutral*

To manage climate change's impacts effectively, it is crucial to have early warning systems for detecting tree stress and assessing mortality risk. The initial step is identifying the key forest ecosystem processes and objectives.[47] These include wood yield, ecosystem carbon, biodiversity, and hydrology.

The potential effects of short-term changes in environmental conditions on trees can be detected through monitoring their growth. Radial tree growth can provide a valuable measure of species responses to drought,[48] with real-time monitoring providing early detection of trees' physiological responses to moisture changes and limitations.[49] Additionally, for adaptive forest management to be effective, it is necessary to identify and predict a tree and a stand's ability to be resilient to a disturbance event.[47] The newly emerging technologies can trace data on harvested log quantity and quality, which can be combined site condition and weather data.[49] Together, this information can be used to refine forest productivity models, especially at the stand level, and provide insights into the adaptive capacity of trees to disturbance events.

4.2.1 Carbon Inventory

Climate-Smart: Inventory of above-ground carbon stocks and carbon accumulation is commonly estimated using timber yield curves, which have been shown to underestimate forest ecosystem carbon.[50] Remote-sensing-based LiDAR estimates can increase the precision of above-ground forest carbon estimates.[51] In addition, LiDAR can improve estimates after a disturbance event.[52] Additional remote sensing applications, like the Global Ecosystem Dynamics Investigation (GEDI) product, offer more cost-effective and timely estimates of forest carbon.[53]

In 2023, the USDA released an update[v] with a request for public comment on the technical guidelines for carbon accounting in the forestry and agricultural sectors. In addition, a USDA report evaluated the role of the forestry sector in generating carbon credits for markets.[54]

4.2.2 Biodiversity

Climate-Smart: The climate-smart forestry approach requires balancing ecosystem benefits. Climate mitigation is not always aligned with other ecosystem benefits like biodiversity. As a result, stand-level management may need to consider tradeoffs between carbon and biodiversity.[55] Different tools have been used to evaluate these tradeoffs and showing varying relationships between carbon stocks and biodiversity.[56–60]

Modeling carbon, biodiversity, and other ecosystem benefit outcomes (such as the availability and quality of water resources) using an integrated approach can help foresters weigh the outcomes and tradeoffs. As climate change affects species distributions, forest managers can benefit from understanding species that are becoming established or extirpated from their landscapes. By combining modeling to predict potential species and monitoring actual species distributions, forest managers can be better able to achieve their biodiversity objectives.

4.2.3 Pest and Pathogens

Climate-Smart: Monitoring is an essential part of any integrative pest management strategy. Early detection of range expansion and infestation severity may be possible with remote sensing technologies. The USDA Forest Service provides the National Insect and Disease Detection Survey data[vi] to help inform forest managers on changes of pests and pathogens within different regions.

Forest managers may also consider using remote sensing and other technologies to monitor forest pest and pathogen outbreaks. The range expansion potential of southern pine beetles can be detected using remote sensing products and monitoring winter dew point temperatures that dip below 0°C.[61] New remote sensing and LIDAR approaches that detect structural differences within the canopy layers provide possible advancements in the early detection and disturbance monitoring of hemlock woolly adelgid.[62] Additionally, eDNA detection is another cost-effective, promising approach compared to conventional detection methods.[63,64]

[iv] This was in the western U.S., where drought- induced mortality is a greater risk to forest land own-ers.

[v] Quantifying Greenhouse Gas Fluxes in Agriculture and Forestry: Methods for Entity-Scale Inventory, Technical Bulletin Number 1939, Office of the Chief Economist, USDA, Washington, DC.

[vi] https://www.fs.usda.gov/foresthealth/applied-sciences/mapping-reporting/detection-surveys.shtml

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APPENDIX A

Appendix A is a table of Major silvicultural strategies used to manage forests in New England, New York, and the Atlantic Maritimes *(Adapted from Duncker et al 2018).*

DECISIONS	BASIC PRINCIPLES OF MAJOR SILVICULTURAL STRATEGIES			
Intensity Scale	Passive	Low	Medium	High
Common Name	Unmanaged forest nature reserve	Close-to-nature forestry	Combined objective forestry	Intensive, even-aged forestry
Triad Class	Ecological Reserves	Multifunctional areas under ecosystem management		High-intensity plantation
1. Naturalness of tree species composition	Only species characteristic of the potential natural vegetation (PNV)	Native or site-adapted species	Tree species suitable for the site	Tree species suitable for the site
2. Tree improvement[†]	No	Not genetically modified or derived from tree breeding programs	Planting material can be derived from tree breeding, but not genetically modified	Planting material can be derived from tree breeding, but not genetically modified
3. Type of regeneration	Natural regeneration / natural succession	Natural regeneration (planting for enrichment or change in tree species composition)	Natural regeneration, planting, and seeding	Natural regeneration, planting, and seeding
4. Successional elements	Yes	Yes	Temporarily	No
5. Machine operation	No	Extensive	Medium	Intensive
6. Soil cultivation	No	No (only to introduce natural regeneration)	Possible (mainly to promote natural regeneration)	Possible
7. Fertilization / Liming	No	No (only if devastated soil‡)	No (only if devastated soil‡)	Possible
8. Application of chemical agents	No	No	Possible as a last resort	Possible
9. Integration of nature conservation	High	High	High	Medium
10. Tree removals	No	Stem (solid volume)	Stem and crown (solid volume)	Up to whole tree
11. Final harvest (and main silvicultural) system	No	Mimics natural disturbances: Single Stem Selection, Group Selection, Irregular shelterwood	All possible: Seed tree, Strip shelterwood, Group shelterwood, Uniform shelterwood, Coppice with standards	All possible: Clearcut (long rotation) preferably used
12. Maturity	No intervention	Long rotation length age of maximum MAI or target diameter according to tree species and stem quality	Medium rotation length age of max. MAI or target diameter according to tree species and stem quality	Short rotation length age of max. financial return (low interest rate)
Wood Production Levels	None	Low	Moderate	High
Carbon Storage	Very high	High	Moderate	Low
Carbon sequestration rates	Low	Low	Moderate	High
Leakage risk	Very high	High	High	Moderate

*The use of genetically modified trees is prohibited by the SFI Forest Management Standard

Current risk management strategies	• Species and age diversity	• Species and age diversity • Thinning • Maintaining access for tending purposes	• Species diversity • Shorter rotation times • Planting local offsite tree species • Maintaining access for tending purposes	• Short rotation • Thinning • Planting out-of-area suitable stock
Climate risk management strategy for wood fiber	Resistance	Resistance: Low vulnerability to changing climate-driven abiotic and biotic impacts, especially non-catastrophic events	Resistance/resilience: Tradeoff between using a diversity strategy and minimizing time exposed to new climate-driven abiotic and biotic impacts	Resilience/transition: Reduces time exposed to changing new climate-driven abiotic and biotic impacts.
Limitations	High risk of infrequent climate-driven stand-replacing events (e.g., fire, windthrow)	Medium risk of infrequent climate-driven stand-replacing events (e.g., fire, windthrow)	Low risk to infrequent climate-driven stand-replacing events (e.g., windthrow)	High risk to species/stand/age-specific climate impacts (e.g., species and age-specific pests and pathogens)

† This might include planting stock produced through genetic modification for Intensive even-aged forestry.
‡ Damaged soil = soil that requires rehabilitation to be productive.

Appendix B is a table of forest carbon tools and other relevant information

TOOL	AREA	DESCRIPTION	SOURCE
CBM-CFS3	Canada (all)	The operational-scale Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3) is an aspatial, stand- and landscape-level modeling framework that simulates the dynamics of all forest carbon stocks required under the Kyoto Protocol (aboveground biomass, belowground biomass, litter, dead wood, and soil organic carbon). It complies with the carbon estimation methods outlined by the Intergovernmental Panel on Climate Change (IPCC).	https://www.nrcan.gc.ca/climate-change/impacts-adaptations/climate-change-impacts-forests/carbon-accounting/carbon-budget-model/13107
Generic Carbon Budget Model (GCBM)	Canada (all)	The GCBM is the next-generation, fully-spatial version of the CBM-CFS3 that the federal government uses for various internal research and collaborative projects.	
FORECAST model	Canada (BC, AB, SK, S. ON, NS)	FORECAST is an ecosystem-based, stand-level forest growth simulator. The model was designed to accommodate various harvesting and silvicultural systems to compare and contrast their effect on forest productivity, stand dynamics, and biophysical indicators of non-timber values. Forest carbon is one of the outputs that can be modeled.	stephen.kull@canada.ca
FORCARB model	Canada (ON)	FORCARB is a U.S. developed model that the government of Ontario has modified for provincial use. The Ontario model is referred to as FORCARB-ON. The model can be used to project carbon storage in harvested wood products.	https://www.ontario.ca/page/forest-carbon
i-Tree Harvest Carbon Calculator	U.S.	The i-Tree Harvest Carbon Calculator (originally known as the PRESTO Wood Calculator) allows land managers and landowners to estimate the amount of carbon stored in harvested wood products. Carbon estimates are based on harvest volume, geographic region, and wood type.	https://harvest.itreetools.org/
Methods for calculating ecosystem and harvested carbon	U.S.	A publication with guidelines and default tables for estimating forest ecosystem carbon pools in the US and storing harvested wood products in use and landfills.	https://www.nrs.fs.fed.us/pubs/8192
FORCARB2	U.S. and Ontario	FORCARB2 produces estimates of carbon stocks and stock changes for forest ecosystems and forest products at 5-year intervals; it includes a new methodology for carbon in harvested wood products, updated initial inventory data, a revised algorithm for dead wood, and now includes public forest land, reserved forest land, and forest land of low productivity.	https://www.nrs.fs.fed.us/pubs/35613
US Forest Carbon Calculation Tool	U.S.	The Carbon Calculation Tool 4.0, CCTv40.exe, is a computer application that reads publicly available forest inventory data collected by the U.S. Forest Service's Forest Inventory and Analysis Program (FIA) and generates state-level annualized estimates of carbon stocks on forest land based on FORCARB2 estimators.	https://www.nrs.fs.fed.us/pubs/2394
EVALIDator	U.S.	Generates user-specified reports on forest inventory estimates, including forest carbon stocks and changes in dry biomass over time, using US Forest Inventory and Analysis (FIA) data.	https://apps.fs.usda.gov/Evalidator/evalidator.jsp
Practitioner's Menu of Adaptation Strategies and Approaches for Forest Carbon Management	U.S.	Decision-support tool for incorporating adaptation considerations into current management objectives.	https://forestadaptation.org/learn/resource-finder/forest-carbon-menu-adaptation-and-mitigation-strategies-and-approaches
USFS Climate Change Resource Center	U.S.	CCRC hosts several informational pages on forest carbon management.	https://www.fs.usda.gov/ccrc/topics

TOOL	AREA	DESCRIPTION	SOURCE
USFS Climate Change Resource Center – Library	U.S.	Library of tools related to forest carbon.	https://www.fs.usda.gov/ccrc/tools?field_topic_category_target_id=5191
Forest-Climate Working Group	U.S.	FCWG hosts webinars that address various topics related to adaptation and mitigation.	https://forestclimateworkinggroup.org/
Securing Northeast Forest Carbon	New England and New York	SNEFC hosts dozens of informational pages on forest carbon management.	https://www.northeastforestcarbon.org/

RESULTS FROM A SURVEY of forest managers and certification managers in the Northeast on favorability ratings of CSF practices and actions.

INTRODUCTION

We conducted a survey of Northeast (ME, NH, VT, upstate NY, and maritime provinces of Canada) forest and certification managers in 2023 to rate climate-smart forestry (CSF) management practices and actions that are applied in that region. The survey also increased manager awareness of CSF practices and actions that are used broadly by the Northeastern forestry community of practice and align with CSF. Increased awareness also allows managers to benchmark their use of CSF practices and actions and identify opportunities for improvement. Managers can also use these results to better integrate existing and new practices that are climate-smart and conform with Objective 9 of the 2022 Sustainable Forestry Initiative's (SFI) Forest Management Standard. This appendix summarizes the survey ratings of CSF actions and practices by forest and certification managers from the Northeast.

The median responses are graphically presented in dot plots for each practice and action. Dot plots are scaled on the three characteristics of each management action and practice: *Application, Effectiveness,* and *Recommendation.* The size of the dot indicates the level of Application currently seen (Substantial, Somewhat, None), the color saturation indicates managers' views on each practice's *Effectiveness* (Substantial, Somewhat, None), and the circle's orientation within each plot indicates the likelihood that managers would *Recommend* (Excellent, Very Good, Good, Fair, Poor) the practice to their peers. Some actions are noted with a yellow "U". This shows that at least 40% of the respondents identified the action's *Effectiveness* as *uncertain*. Combined, the three metrics help users identify:

- Actions that managers are currently taking and are aligned with CSF.
- Actions that managers are not taking but recommend to fellow managers.
- Actions that managers are not taking and are recommended.
- Actions that likely require additional study because this community of practice is uncertain of their efficacy.
- Actions that managers are not taking but that may pose opportunities for development or new use.

Managers should consider CSF practices and actions that align with their organization's goals and objectives and are appropriate to local conditions. Many highly rated practices and actions may not meet these criteria for every landowner and management situation. Also, the survey results identified many emerging but untested practices and actions that are not highly recommended. In the spirit of continuous improvement, some managers may elect to test the use of some of these emerging practices or actions.

Figures 1 through 6 summarize the ratings of CSF adaptation and mitigation practices by forest managers. These practices relate to operational considerations in stand management and harvest operations. CSF practices mostly relate to forest operations and fall under Objective 9 of the SFI's 2022 Forest Management Standard. The CSF practice ratings were averaged by practice and major category (e.g., Pest and Pathogen Management) within each category and presented in Figure 1. Figures 2 through 6 indicate average ratings for specific CSF practices within each category.

Figures 7 through 12 summarize the rating of CSF adaptation and mitigation actions by certification managers. Actions were general strategies and policies applied by the company to achieve sustainable management of forest resources and conform with certification requirements. Most were not operational actions. The CSF actions were grouped by objective in the SFI's Forest Management Standard. Two groups of objectives were aggregated (Objectives 5 and 6, and Objectives 15 and 16), and Objective 9 was divided into Adaptation (9.1) and Mitigation (9.2). The action ratings were averaged for each SFI objective and presented in Figure 7. Figures 8 through 12 indicate average ratings for specific CSF actions within each objective category.

FIGURE 1. Average rating of practices for five adaptation categories and six mitigation categories. Categories are arranged from having the practices with the highest average rating to least average rating among mitigation categories and adaptation categories. Practices within categories were rated by forest managers.

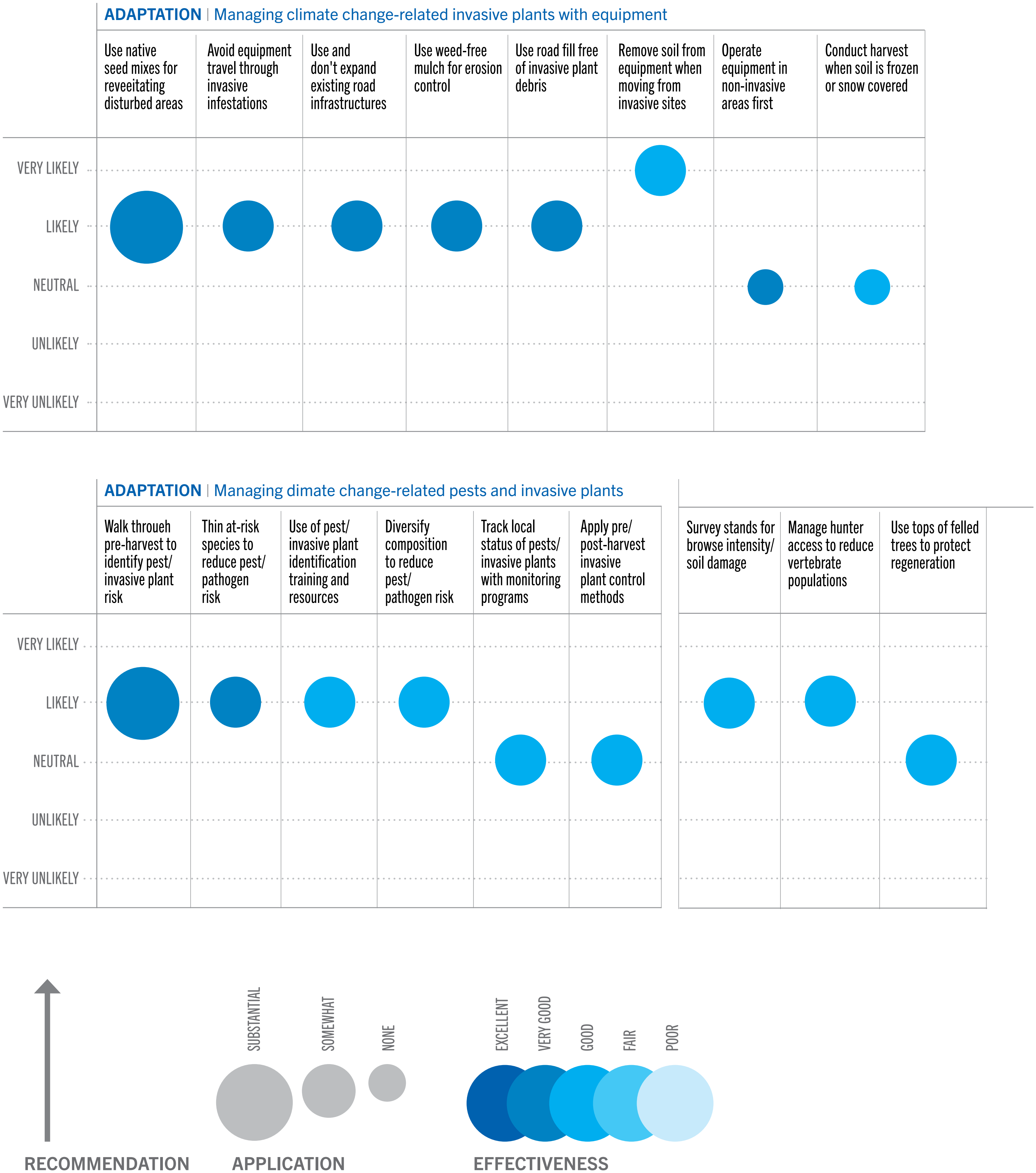

FIGURE 2. Average rating for practices within three adaptation categories: equipment management for invasive plants, pests and invasive plants, and over-abundant vertebrate species. Practices were arranged from most favorably rated practices to least favorably rated practices within each adaptation topic. Practices were rated by forest managers.

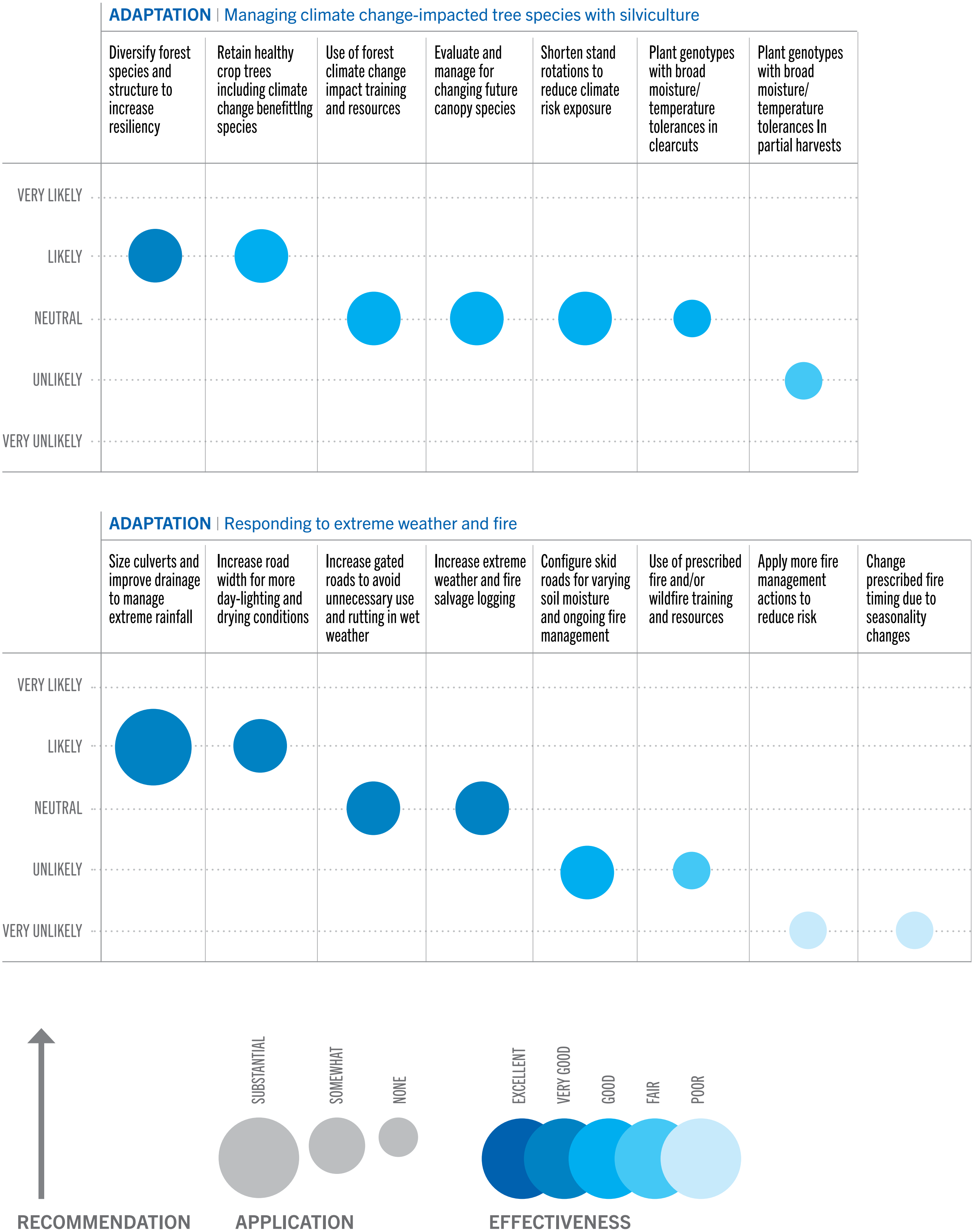

FIGURE 3. The average ratings for practices within two adaptation categories: silviculture and extreme weather/fire. Practice ratings were arranged from most favorably rated practices to least favorably rated practices within each adaptation topic. Practices were rated by forest managers.

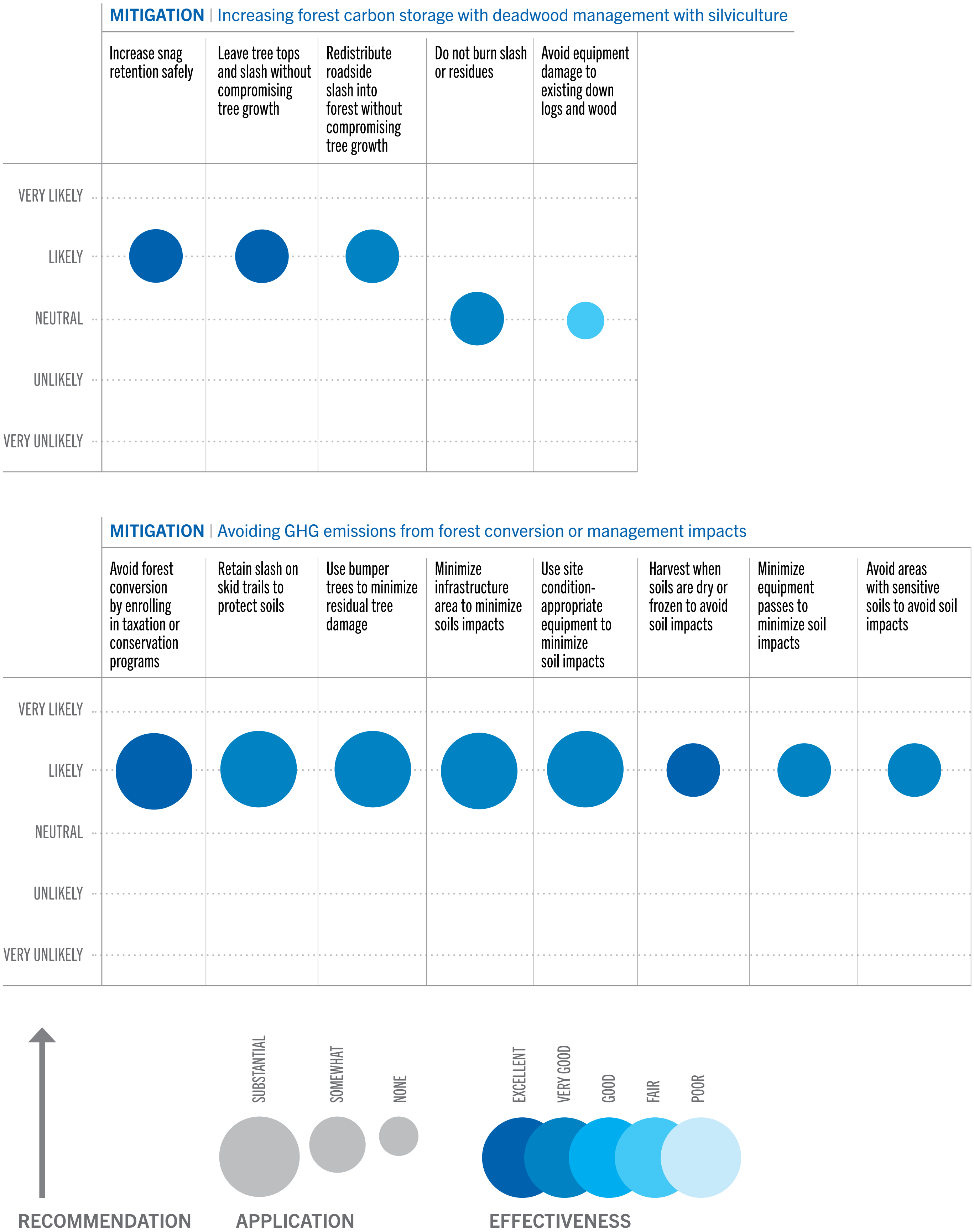

FIGURE 4. The average rating of practices within two mitigation categories: deadwood management and equipment use/conversion. Practice ratings were arranged from most favorably rated practices to least favorably rated practices within each mitigation topic. Practices were rated by forest managers.

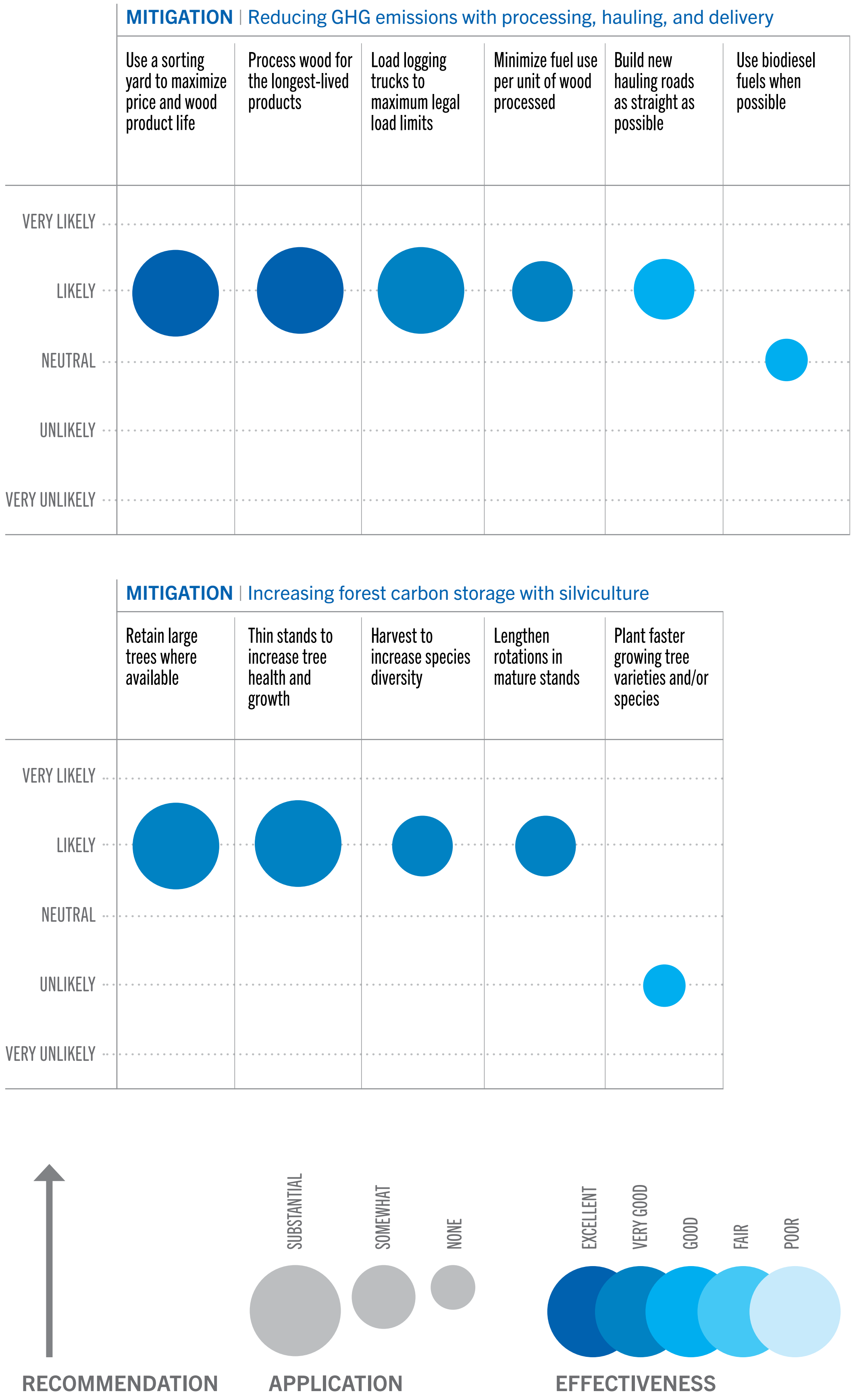

FIGURE 5. The average rating of mitigation practices within two mitigation categories: processing/hauling and silvicultural practices. Practice ratings were organized within each mitigation topic from most favorably rated practices to least favorably rated practices. Practices were rated by forest managers.

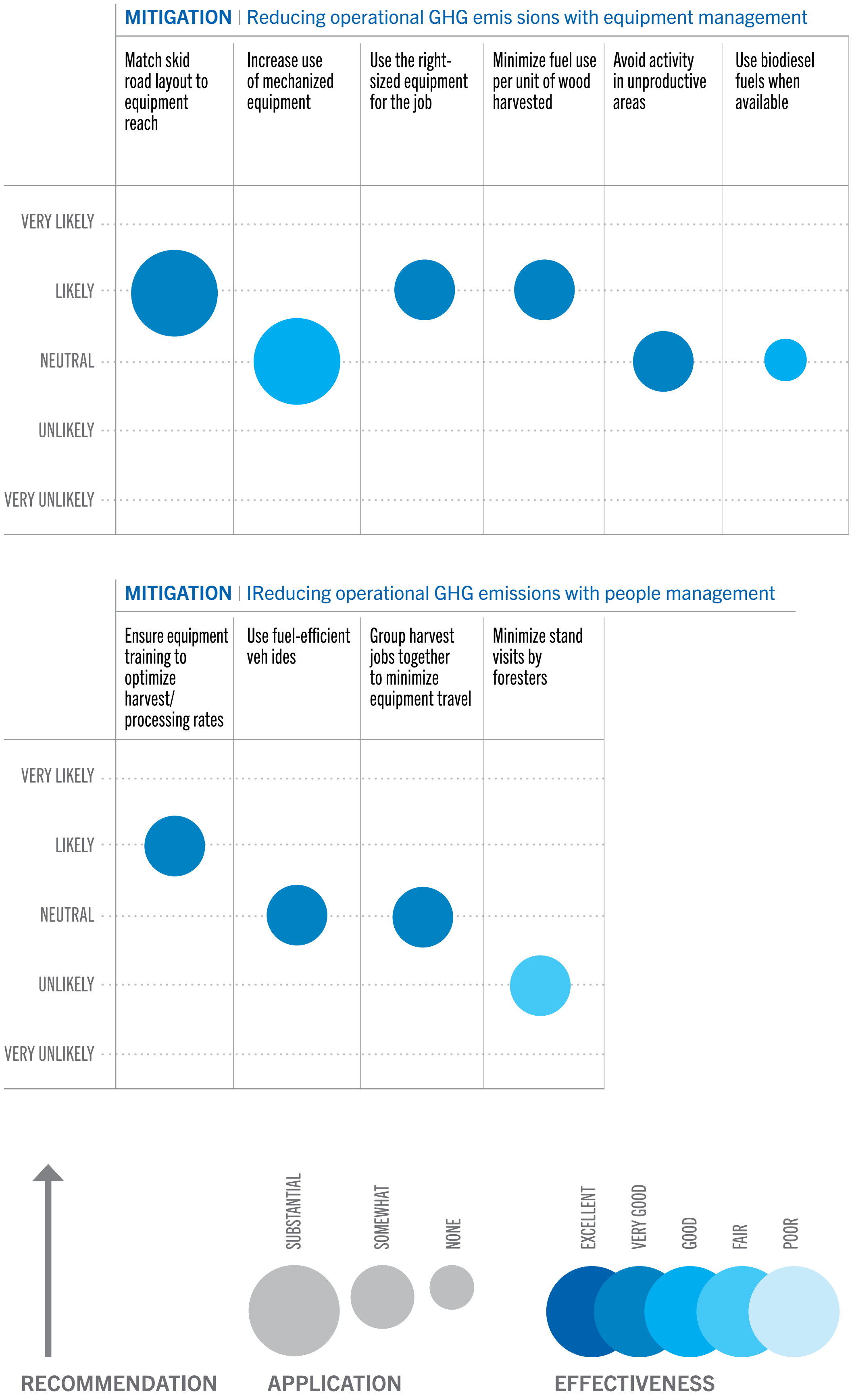

FIGURE 6. The average rating of mitigation practices within mitigation topics: equipment management and people management. Practice ratings were arranged from most favorably rated practices to least favorably rated practices within each mitigation topic. Practices were rated by forest managers.

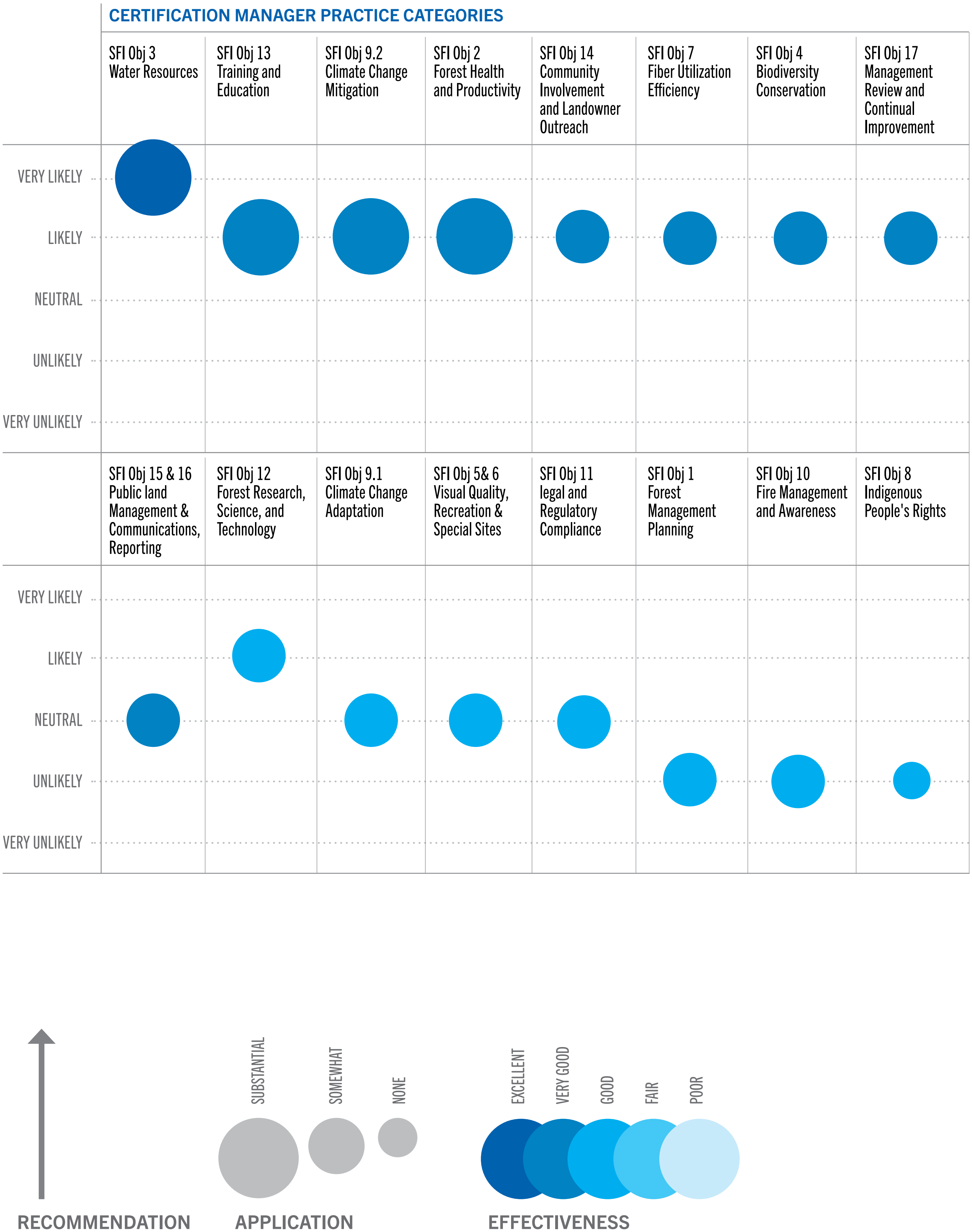

FIGURE 7. The averaged rating of actions for each Objective of the SFI 2022 Forest Management Standard. Objective ratings were arranged from most favorably rated objective to least favorably rated objective. Actions within Objective 9 (Climate Smart Forestry) were subdivided into Objective 9.1 (mitigation) and Objective 9.2 (adaptation). Actions within Objectives 5 and 6, and 15 and 16 were combined into two categories for visualization efficiency.

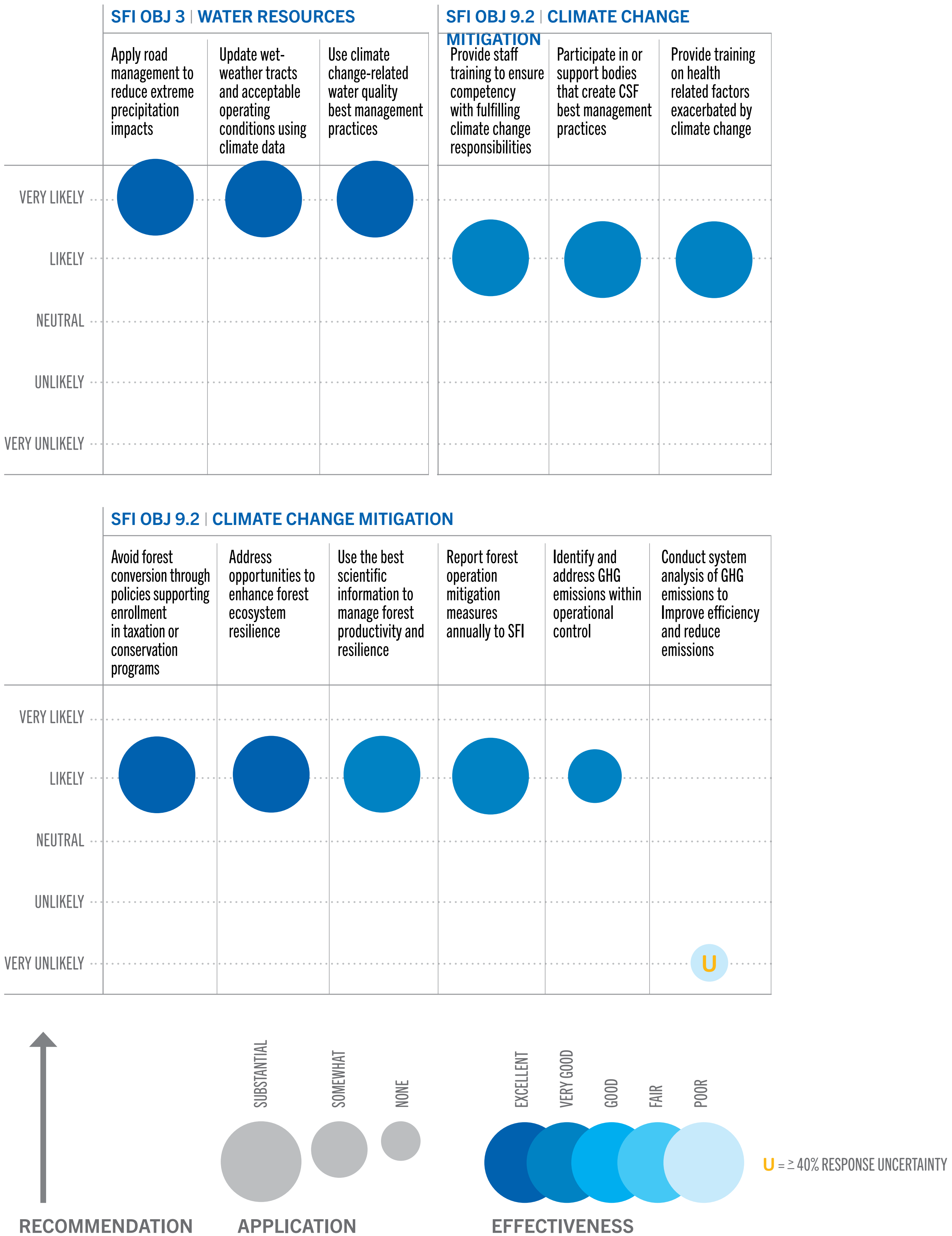

FIGURE 8. The average ratings for actions within Objective 3, 9.2, and 13 of the SFI 2022 Forest Management Standard. Action ratings were arranged in order of most favorably rated objectives to least favorably rated objectives. Actions were rated by certification managers.

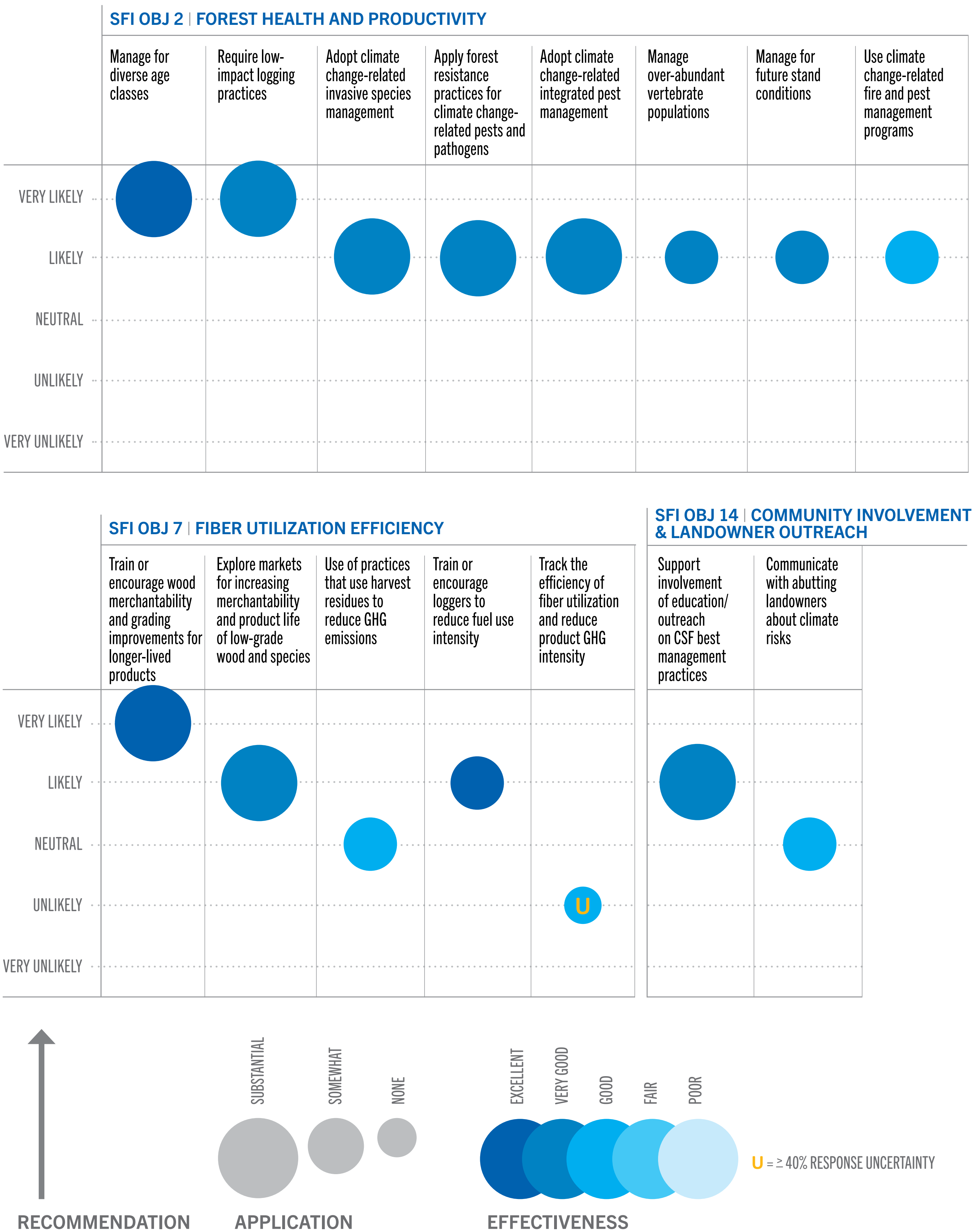

FIGURE 9. The average ratings for actions with four Objectives 2, 7, and 14 of the SFI 2022 Forest Management Standard. Actions were rated by certification managers. Action ratings were arranged in order of most favorably rated action to least favorably rated action within each Objective. Actions were rated by certification managers.

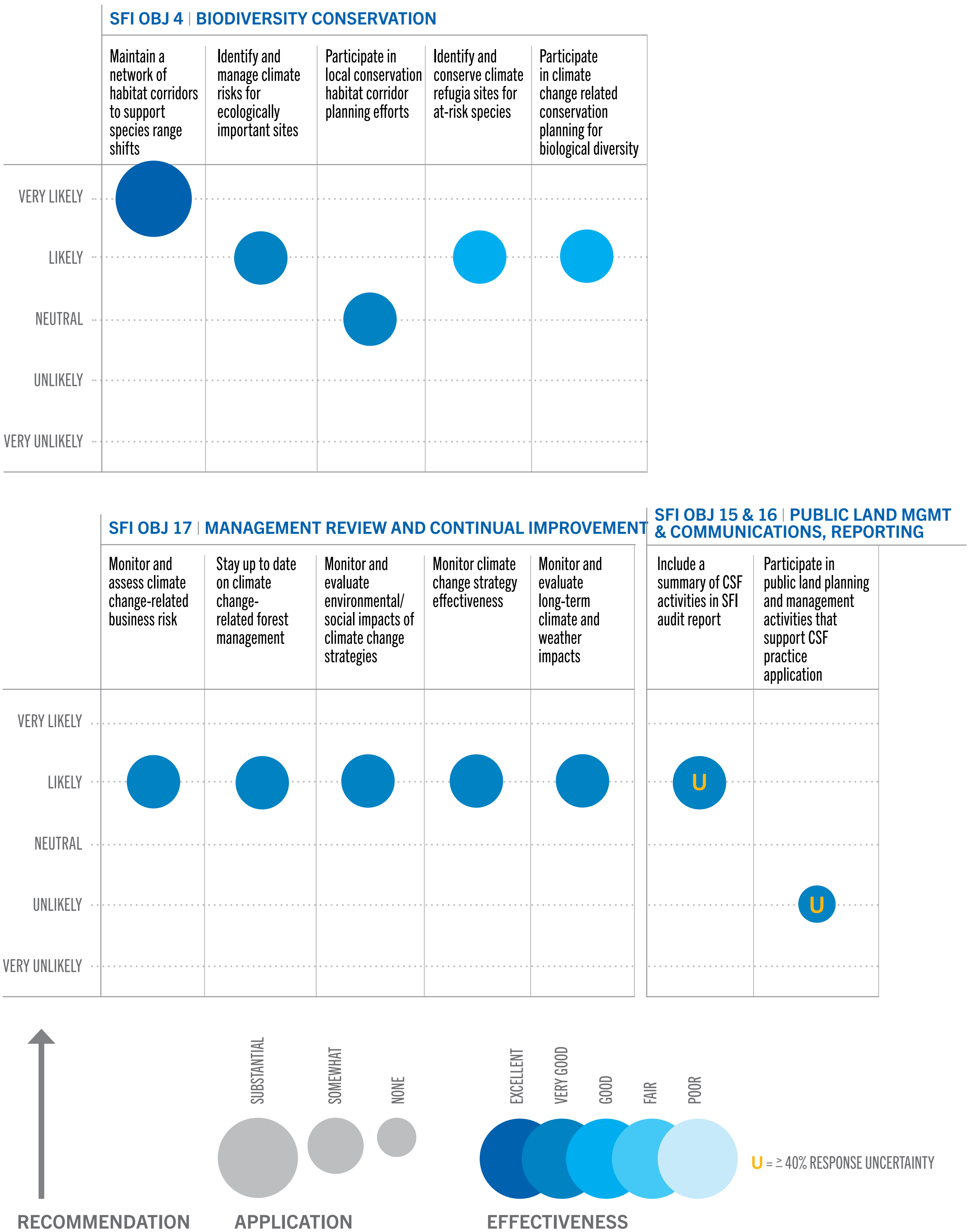

FIGURE 10. The average ratings of actions for Objectives 4, 15, 16, and 17 of the SFI 2022 Forest Management Standard. Action ratings were arranged in order of most favorably rated actions to least favorably rated action within each Objective. Actions were rated by certification managers.

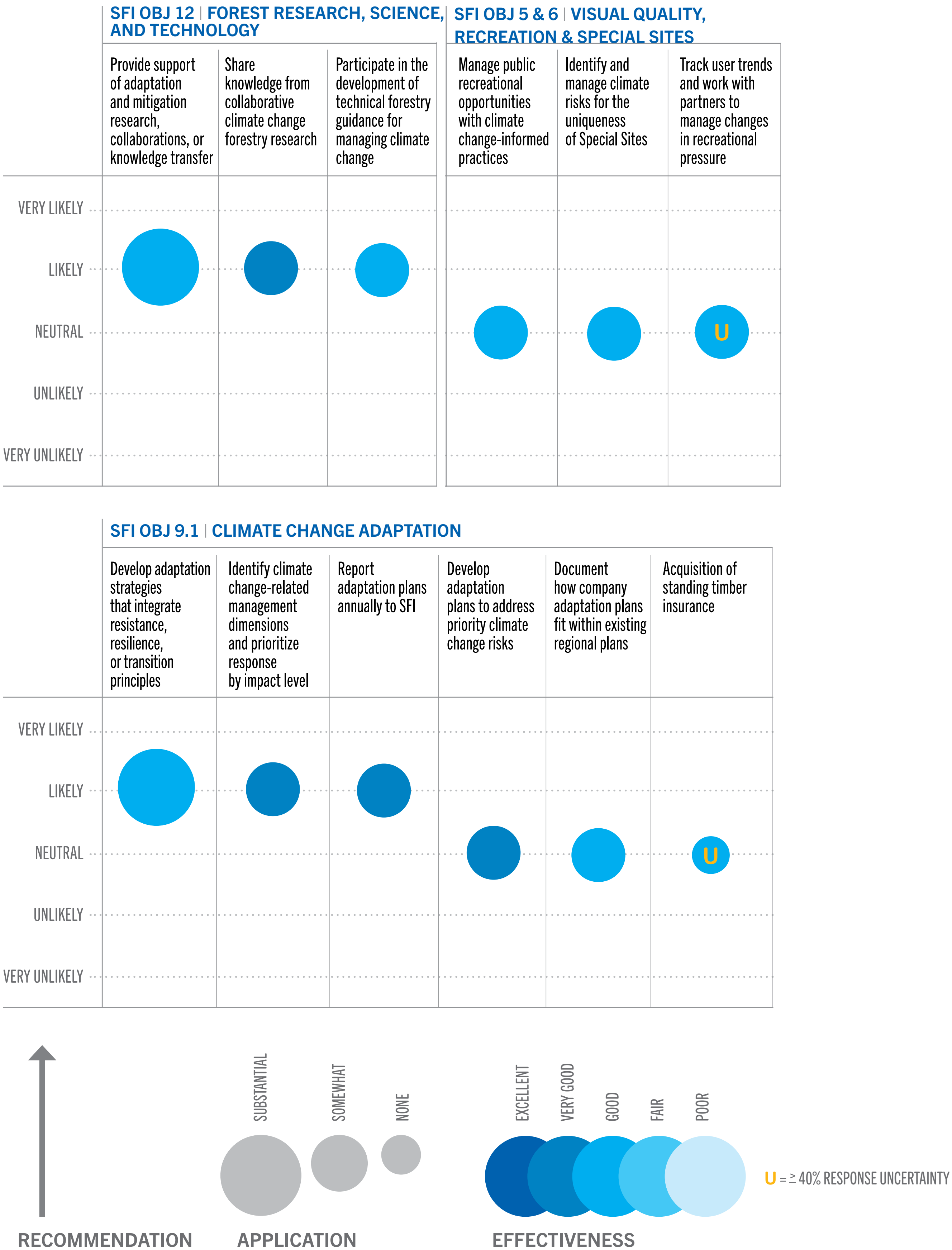

FIGURE 11. Average ratings for actions within Objectives 5, 6, 9.1, and 12 of the SFI 2022 Forest Management Standard. Action ratings were arranged in order of most favorably rated action to least favorably rated action within each Objective. Actions were rated by certification managers.

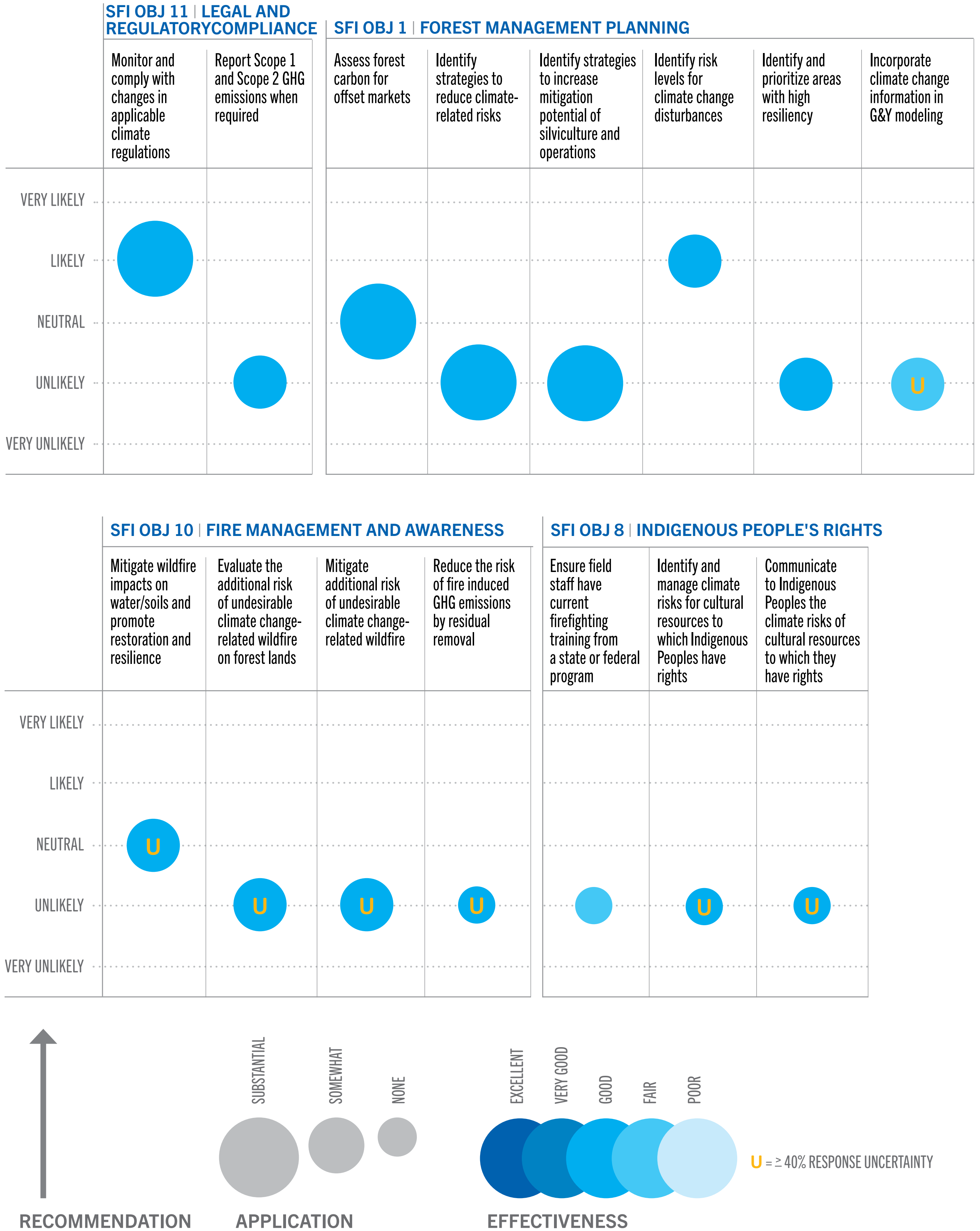

FIGURE 12. The average ratings for actions within Objectives 1, 8, 10, and 11 of SFI's Forest Management Standard. Action ratings were arranged in order of most favorably rated action to least favorably rated action within each Objective. Actions were rated by certification managers.

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