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Climate-Smart Forestry: Characteristics, Benefits, and Trade-Offs

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EXECUTIVE SUMMARY

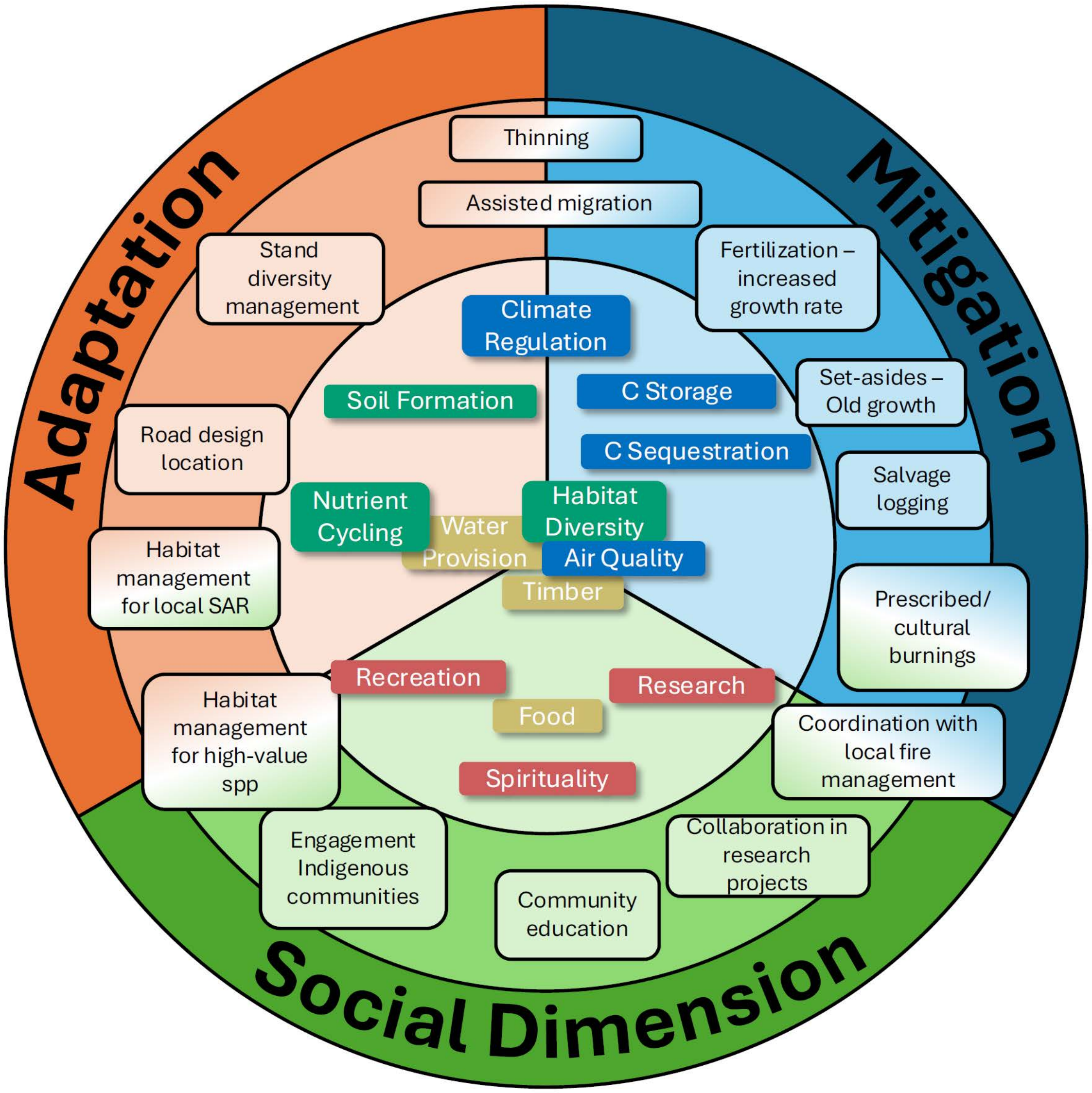
- Climate-Smart Forestry (CSF) has gained international momentum as a forward-looking framework that aligns forest management with climate adaptation, mitigation, and the preservation of social values. In Canada, many of the principles at the core of CSF, such as climate-related risk reduction, biodiversity conservation, and engagement with Indigenous communities, are already deeply rooted in sustainable forest management. This positions Canada well to advance CSF, not through wholesale reinvention but by expanding and reframing existing forest management tools and practices.

- Adaptation has emerged as the most immediately actionable priority within CSF in Canada. Practical strategies such as conducting climate vulnerability assessments, diversifying forest composition, and applying fire risk reduction measures are already in use, often supported by federal and provincial guidance. Mitigation measures (e.g., enhancing carbon storage and undertaking afforestation) are also advancing, but their implementation is influenced by land availability, operational constraints, and longer return horizons. As a result, these efforts have attracted the majority of CSF-related funding and research initiatives globally.

- Distinct from many international approaches, the social dimension of CSF plays a central role in Canada, reflecting legal, cultural, and moral obligations to Indigenous Peoples. Case studies from forest management companies are outlined and demonstrate how partnerships with Indigenous communities are shaping inclusive, climate-responsive forestry practices.

- A key challenge for CSF implementation remains the management of ecosystem service trade-offs, especially between timber production, biodiversity, carbon storage, and water regulation. Few Canadian studies have quantified these trade-offs at operational scales. Still, the report draws on emerging literature and international models to offer insight.

- Despite growing alignment between CSF and sustainable forest management, widespread implementation in Canada is constrained by regulatory fragmentation, limited workforce capacity, economic uncertainty, and persistent knowledge gaps. However, promising initiatives, including precision monitoring networks, adaptive silvicultural trials, and decision-support tools, are closing the gap between theory and practice.



Interconnections among CSF components (outer circle), forest management strategies (middle circle), and ecosystem services (inner circle)
[Note: The overlapping and interrelated nature of these elements highlights the complexity of identifying optimal CSF practices that simultaneously achieve CSF objectives and deliver desired ecosystem services outcomes while minimizing potential trade-offs]

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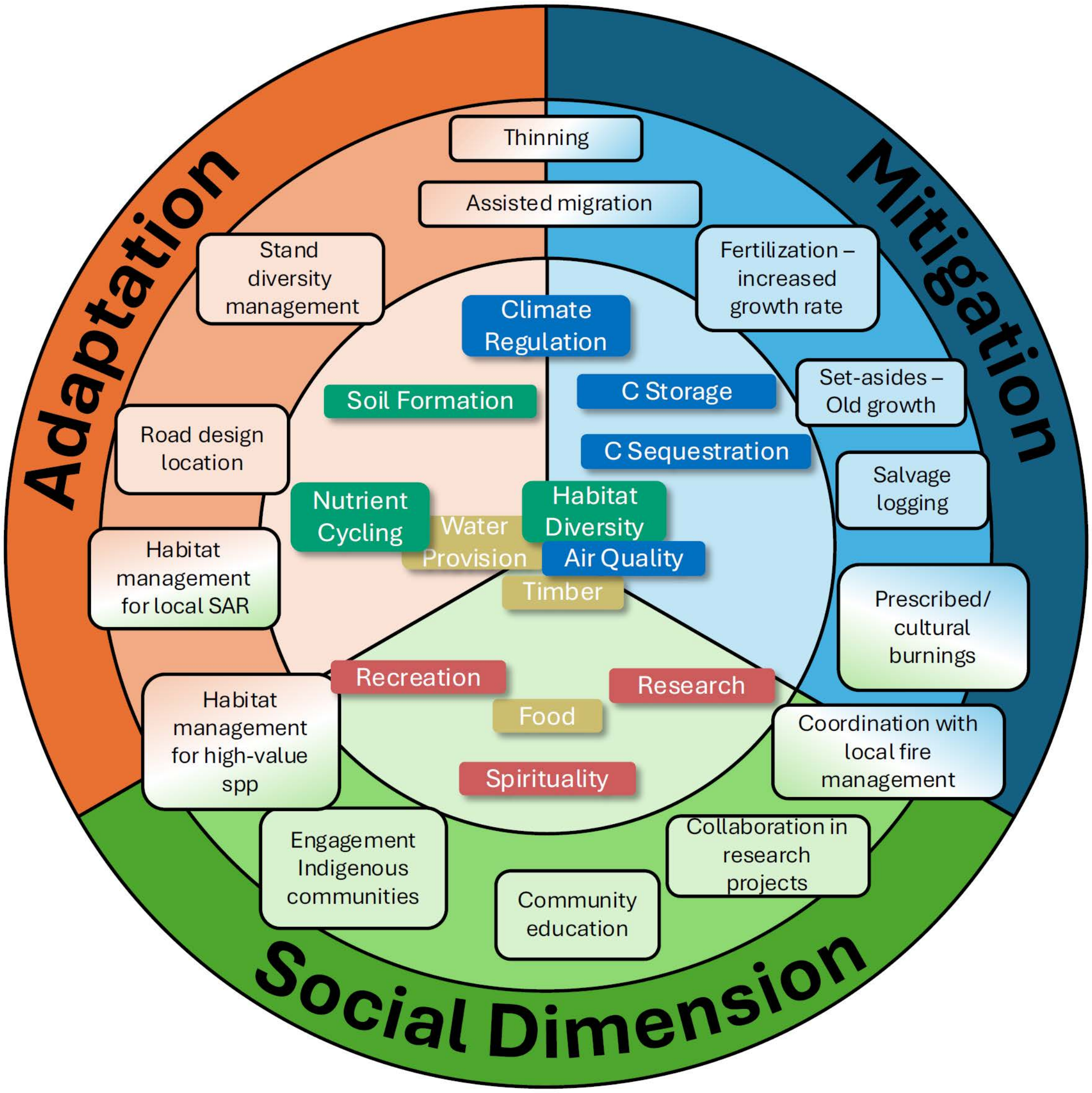
- La foresterie intelligente face au climat (FIC) a gagné en importance sur la scène internationale en tant que cadre prospectif qui aligne l'aménagement forestier sur l'adaptation au climat, l'atténuation et la préservation des valeurs sociales. Au Canada, bon nombre des principes au cœur de la FIC, tels que la réduction des risques liés au climat, la conservation de la biodiversité et l'engagement avec les communautés autochtones, sont déjà profondément ancrés dans l'aménagement forestier durable (AFD). Cela place le Canada dans une position favorable pour faire progresser la FIC, non pas par une refonte complète, mais en élargissant et en reformulant les outils et pratiques existants en matière d'aménagement forestier.

- L'adaptation est apparue comme la priorité la plus immédiatement exploitable dans le cadre de la FIC au Canada. Des stratégies pratiques telles que la réalisation d'évaluations de la vulnérabilité climatique, la diversification de la composition des forêts et l'application de mesures de réduction des risques d'incendie sont déjà en cours, souvent soutenues par des directives fédérales et provinciales. Des mesures d'atténuation (p. ex. l'augmentation du stockage de carbone et le recours à l'afforestation) progressent également, mais leur mise en œuvre est influencée par la disponibilité des terres, les contraintes opérationnelles et des horizons de retour plus longs. En conséquence, ces efforts ont attiré la majorité du financement et des initiatives de recherche liés à la FIC à l'échelle mondiale.

- Distincte de nombreuses approches internationales, la dimension sociale de la FIC joue un rôle central au Canada, reflétant les obligations légales, culturelles et morales envers les peuples autochtones. Des études de cas provenant de sociétés d'aménagement forestier sont présentées et montrent comment les partenariats avec les communautés autochtones façonnent des pratiques forestières inclusives et adaptées au climat.

- Un défi clé pour la mise en œuvre de la FIC demeure la gestion des arbitrages entre services écosystémiques, notamment entre la production de bois, la biodiversité, le stockage de carbone et la régulation de l'eau. Peu d'études canadiennes ont quantifié ces arbitrages à l'échelle opérationnelle. Néanmoins, le rapport s'appuie sur une littérature émergente et sur des modèles internationaux pour fournir des pistes de réflexion.

- Malgré l'alignement croissant entre la FIC et l'AFD, une mise en œuvre généralisée au Canada reste limitée par la fragmentation réglementaire, la capacité restreinte de la main-d'œuvre, l'incertitude économique et des lacunes persistantes en matière de connaissances. Toutefois, des initiatives prometteuses, incluant des réseaux de suivi de précision, des essais sylvicoles adaptatifs et des outils d'aide à la décision, contribuent à combler l'écart entre la théorie et la pratique.



Interconnexions entre les composantes de la FIC (cercle extérieur), les stratégies de gestion forestière (cercle intermédiaire), et les services écosystémiques (SE) (cercle intérieur). La nature interconnectée et chevauchante de ces éléments illustre la complexité d'identifier des pratiques optimales de FIC qui permettent à la fois d'atteindre les objectifs de la FIC, de fournir les résultats souhaités en matière de SE, tout en minimisant les compromis potentiels.

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CLIMATE-SMART FORESTRY: CHARACTERISTICS, BENEFITS, AND TRADE-OFFS

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January 2026

ABSTRACT

Climate change is altering the structure and function of Canada's forests through rising temperatures, shifting precipitation patterns, and intensifying natural disturbances. While sustainable forest management has long guided responsible forestry in Canada, it has not fully integrated climate adaptation and mitigation as core objectives. In response, Climate-Smart Forestry (CSF) has emerged as a framework that incorporates adaptation, mitigation, and the preservation of social values into forest planning and operations. This report explores how CSF builds on Canada's sustainable forest management legacy by characterizing and contextualizing existing tools, policies, and practices with the realities of a changing climate. It presents CSF's three core components: adaptation to climate vulnerability, mitigation to enhance carbon sequestration, and the social dimension, emphasizing equity, Indigenous rights, and intergenerational value, and examines how these are being operationalized across Canadian forest landscapes. Case studies illustrate on-the-ground applications, including vulnerability assessments, assisted migration, and Indigenous-led practices such as cultural burning. The report also identifies emerging trade-offs among ecosystem services (e.g., biodiversity, wood supply, carbon storage, and water regulation), offering insights into how spatial planning and decision-support systems can help balance competing objectives. While CSF holds strong potential to strengthen forest resilience and contribute to climate change mitigation, its advancement is hindered by several barriers. Key challenges include regulatory fragmentation, economic constraints, along with gaps in data, capacity, and cross-jurisdictional coordination. Despite these obstacles, CSF should not be viewed as a replacement for sustainable forest management but as its natural progression, a forward-looking approach that leverages Canada's institutional and scientific capacity to meet climate and sustainability goals more holistically.

KEYWORDS
adaptation, climate change, climate-smart forestry, ecosystem services, forest management, forestry, mitigation, social values, sustainable forest management, trade-offs

FORESTERIE INTELLIGENTE FACE AU CLIMAT : CARACTÉRISTIQUES, BÉNÉFICES ET COMPROMIS

BULLETIN TECHNIQUE NO 1097
Janvier 2026

RÉSUMÉ

La structure et la fonction des forêts changent au Canada en raison des changements climatiques qui augmentent les températures, modifient les régimes de précipitations et intensifient les perturbations naturelles. Bien que les normes d'aménagement forestier durable guident depuis longtemps les pratiques de foresterie responsable au Canada, elles n'ont pas pleinement intégré des mesures d'adaptation et d'atténuation aux changements climatiques dans leurs objectifs de base. Pour combler ce besoin, la foresterie intelligente face au climat (FIC) a émergé comme cadre de référence en matière d'adaptation, d'atténuation et de préservation des valeurs sociales dans la planification et opérations forestières. Le présent rapport explore de quelle façon la FIC s'appuie sur l'héritage de l'aménagement forestier durable au Canada pour caractériser et contextualiser les outils, politiques et pratiques existantes face aux réalités d'un climat qui change. Il décrit les trois principales composantes de la FIC : l'adaptation à la vulnérabilité climatique, l'atténuation pour améliorer la séquestration du carbone et la dimension sociale, en mettant l'accent sur l'équité, les droits autochtones et les valeurs intergénérationnelles, et examine de quelle façon ces composantes sont opérationnalisées dans l'ensemble du paysage forestier canadien. Des études de cas illustrent l'application de ces composantes sur le terrain, notamment des exemples d'évaluation de vulnérabilité, de migration assistée et de pratiques autochtones telles que le brûlage culturel. Le rapport fait aussi ressortir des compromis émergents parmi les services écosystémiques (p. ex. biodiversité, approvisionnement en bois, stockage du carbone et régulation de l'eau), offrant un aperçu sur la façon dont la planification spatiale et les systèmes de soutien à la prise de décision peuvent aider à trouver un équilibre entre des objectifs contradictoires. Bien que la FIC soit fortement susceptible de renforcer la résilience des forêts et de contribuer à l'atténuation des changements climatiques, plusieurs barrières ralentissent sa progression. Parmi les principaux défis, il y a la fragmentation règlementaire, les contraintes économiques ainsi que l'insuffisance de données, la capacité en matière de main d'œuvre et la coordination entre juridictions. En dépit de ces obstacles, la FIC ne devrait pas être considérée comme une solution de remplacement à l'aménagement forestier durable, mais comme son évolution naturelle, c'est-à-dire une approche prospective qui tire parti de la capacité institutionnelle et scientifique du Canada pour atteindre ses objectifs en matière de changements climatiques et de durabilité de façon plus holistique.

MOTS-CLÉS
adaptation, aménagement forestier, aménagement forestier durable, atténuation, changements climatiques, compromis, foresterie, foresterie intelligente face au climat, services écosystémiques, valeurs sociales

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CLIMATE-SMART FORESTRY: CHARACTERISTICS, BENEFITS, AND TRADE-OFFS

1.0 INTRODUCTION

Adapting to, and mitigating, the risks posed by climate change is now a central challenge for forest management in the 21st century. Climate change is expected to affect forests differently depending on the region, with Canada's boreal and temperate forests expected to experience significant warming as a result of a projected rise in mean annual temperatures of 2–7°C by 2100 (Feng et al. 2014). More specifically, regional climate projections indicate warmer and drier winters in the Boreal West, Montane, and Pacific Forest regions, in contrast with anticipated increased precipitation and flood risks in eastern Canada (Lemprière et al. 2008). These changing climate patterns are already intensifying wildfire frequency and severity (BC Wildfire Service 2025; Boulanger et al. 2024), escalating drought stress (Allen et al. 2010; Michaelian et al. 2011), and increasing vulnerability to insect and pest outbreaks (Kalamandeen et al. 2023; Lemprière et al. 2008; Volney et al. 2000).

From the 1990s to 2008, Canada's managed forests acted as a carbon sink of 28 Tg C per year (Kurz et al. 2013) but have since shifted toward being a net carbon source due to several large-scale natural disturbances. In the 2000–2020 period, insect outbreaks alone were estimated to release 270 Mt C in British Columbia (Kurz et al., 2008), and wildfires contributed emissions of 1,100 Mt CO_2 from managed forests in 2023 (Boulanger et al. 2024; Environment and Climate Change Canada 2025). These trends threaten to permanently reverse the role of Canadian forests as net carbon sinks, undermining their long-term contribution to global climate goals (NRCan 2025d). Simultaneously, altered temperature and precipitation regimes have driven documented shifts in vegetation community compositions as species attempt to track their climatic niches (e.g., Solarik et al. 2020), with major implications for biodiversity, productivity, recruitment, and ecosystem function (Beckage et al. 2008; Lenoir et al. 2008; McCarragher et al. 2011; Reich et al. 2022; Solarik et al. 2016; Walck et al. 2011). The growing evidence and the uncertainty associated with such changes influencing current and future forest dynamics raise urgent questions about how best to manage Canada's forests to minimize their vulnerability and bolster resilience to global stressors (Messier et al. 2019; Mina et al. 2022).

Sustainable forest management (SFM) is an adaptive, dynamic, evolving framework designed to maintain and, where possible, enhance the environmental, social, and economic values of forests (CCFM 2008; United Nations General Assembly 2008; Williamson et al. 2017). In Canada, SFM is mandated by a series of comprehensive federal, provincial, and territorial regulations (Gilani et al. 2020; NCASI 2025; NRCan 2023b) and reinforced by voluntary best management practices and third-party forest certification. Canada's initial third-party forest certification initiative was established in 1996 under the Canadian Standards Association[1] and was

[1] CSA Z809, *Sustainable Forest Management* (CSA Z809:16 [R2021]; CSA Group, https://www.csagroup.org/store/product/2424363/?srsltid=AfmBOorX15CAzcUSKmG2JtS0_UGwW2GLDeCKjHD_B

developed to operationalize the Montréal Process in Canada. The Montréal Process established a set of internationally agreed-upon criteria and indicators for the conservation and sustainable management of temperate and boreal forests (Montréal Process 2019; Montréal Process Working Group 2023). Since 1992, when Canada became a signatory to the United Nations Framework Convention on Climate Change, managing and enhancing forest carbon sinks has been central to national climate commitments, driving widespread adoption of SFM practices (United Nations 1992). As a result, understanding the effects of climate change on forests and facilitating adaptation of the forest ecosystem to enable the continued contributions to societal needs has been an important axis of SFM in Canada (Ohlson et al. 2005; Spittlehouse et al. 2004).

Over the past two decades, growing awareness of climate risks prompted efforts to more extensively integrate climate change considerations into SFM. Early contributions include frameworks for decision-making in forest adaptation (Ohlson et al. 2005) and the development of "climate-smart" approaches to forestry (Nitschke et al. 2008). Collectively, these efforts have since been leveraged and synthesized into federal and provincial guidance documents (CCFM 2008; Edwards et al. 2012; 2015; Johnston et al. 2009; Lemprière et al. 2008) that have progressively led to more comprehensive incorporation of climate-related aspects into Canadian SFM. Concurrently, third-party forest certification systems such as the Forest Stewardship Council (FSC) and the Sustainable Forestry Initiative (SFI) now embed climate resilience, ecosystem restoration, and carbon management into their standards. For example, FSC integrates climate change considerations (risks and awareness) into harvest calculations and landscape objectives (Forest Stewardship Council 2020), while SFI's objective 9 (Climate-Smart Forestry [CSF]) requires certified organizations to identify climate risks, plan for adaptation, and reduce climate-related impacts (Sustainable Forestry Initiative 2022).

Despite these advances, Canadian forests remain vulnerable to climate change (Antwi et al. 2024a; Roshani et al. 2022). Forest managers face challenges with navigating the complex regulatory environments, balancing competing adaptation and mitigation objectives, and operating under resource constraints amid persistent uncertainty about regional climate impacts and the effectiveness of emerging treatments. Although the forest sector recognizes the need for climate-responsive strategies (Ameztegui et al. 2018), SFM has only recently begun to explicitly link climate risks with operational responses, limiting the forest sector's ability to build long-term resilience through SFM implementation alone (Williamson et al. 2017).

The challenges posed by climate change to forestry are not unique to Canada. In Europe, forest managers have long been engaged in discussions about adapting forest management to sustain a broad suite of ecosystem services (ES; e.g., biodiversity conservation, water regulation, and recreation) under changing climatic conditions (Yousefpour et al. 2017). These discussions have underscored the dual role forests have in climate mitigation, both as carbon sinks and as renewable sources of wood products that can substitute carbon-intensive alternative options (e.g., fossil fuels, steel, and concrete) (Kurz et al. 2013; Nabuurs et al. 2017; Smyth et al. 2017;

X8z9h1YAjzHk0rC), has been withdrawn and replaced with PEFC Canada—Sustainable Forest Management Standard PEFC CAN ST 1001:2025 (https://www.pefccanada.org/pefc-standards/forest-management-certification.htm).

Verkerk et al. 2020). The incorporation of climate mitigation and adaptation as guiding frameworks for natural resource management predates their formal adoption in forestry. For instance, the Food and Agriculture Organization of the United Nations (FAO) introduced the concept of Climate-Smart Agriculture in 2013, marking the first formal usage of the construct "Climate-Smart" (Food and Agriculture Organization of the United Nations, 2013). Later, the concept was repurposed for forestry with the appearance of CSF in 2015, with Nabuurs and colleagues being the first to apply the term in a European context (Nabuurs et al. 2015). Building on this foundation, in 2016, the European Union (EU) COST Action Working Group 1 was formed, composed of international researchers and practitioners, to further refine and develop the CSF concept, with the explicit aim of integrating climate change adaptation and mitigation into forest management (Nabuurs et al. 2017; Verkerk et al. 2020). These efforts culminated in 2020 with publication of the results of the Action Working Group 1, which provided the first official definition of CSF (Bowditch et al. 2020). Since then, the field has gained momentum, generating over 900 related publications between 2020 and 2024.

CSF is a holistic management framework that extends SFM by explicitly targeting three interdependent objectives: (1) facilitating forest adaptation to climate change, (2) mitigating climate change through carbon sequestration and reduction of carbon emissions, and (3) securing the social and economic value of forests (Bowditch et al. 2020; Tognetti et al. 2022; Verkerk et al. 2020). In this light, CSF clarifies and strengthens previously implicit components within SFM.

Although CSF offers a cohesive framework for integrating climate adaptation and mitigation, its practical application requires navigating complex trade-offs among multiple ES (e.g., timber production, water regulation, carbon storage) (D'Amato et al. 2021; Littlefield et al. 2022). ES are defined as the benefits humans derive from ecosystem functions (Constanza et al. 1997). The provision of these services is dynamic, varying across spatial and temporal scales in response to landscape heterogeneity, stand succession, and natural and human-induced disturbances (Qiu et al. 2018). CSF interventions designed to enhance one service can inadvertently diminish another. For instance, strategies that are aimed at maximizing carbon storage through maintaining higher stocking levels may reduce stand-level structural and compositional complexity, reducing adaptation potential (D'Amato et al. 2011). Conversely, promoting structural diversity to improve adaptive capacity or habitat availability for certain species can reduce overall carbon sequestration potential per unit area (Littlefield et al. 2022). Such inherent incompatibilities necessitate explicit prioritization and evaluation of service outcomes. Systematic identification of ES priorities and quantification of possible synergies and trade-offs among management actions are becoming increasingly essential for managers to consider (Littlefield et al. 2022). Decision-support tools that integrate spatially explicit modelling of multiple ES can help forest managers evaluate scenario outcomes, optimize co-benefits, and minimize conflicts; however, they remain in their infancy (D'Amato et al. 2021; Littlefield et al. 2022).

Beyond identifying and balancing trade-offs among ES, operationalizing CSF comes with confronting multiple technical and logistical barriers, which include sourcing, growing, and planting future climate-adapted tree species (P. W. Clark et al. 2023), leading to delaying or restricting the development and application of adaptation treatments (Haase et al. 2017). Regulatory complexity and restrictions can further impede planning and implementation, as overlapping, conflicting, or overly prescriptive policies may constrain the suite of management activities permissible within a given jurisdiction or across jurisdictions (NCASI 2025). Uncertainty regarding the long-term effectiveness of novel silvicultural interventions aimed at climate adaptation may also hinder their incorporation in forest management plans due to a lack of robust, region-specific evidence to support productivity and sustainability (Ameztegui et al. 2018; Antwi et al. 2024a; 2024b). Finally, implementing CSF practices may be further restricted in both scope and scale due to the increased costs associated with planting, harvesting, and additional planning (Cyr et al. 2022; Phillips 2004). Together, these factors underscore that maximizing the benefits of CSF requires not only careful prioritization of objectives and goals, as well as subsequent actions, but also coordinated efforts to resolve technical, regulatory, and economic challenges.

Given this context, the objectives of this report are four-fold: (1) define and contextualize CSF, (2) review adaptation and mitigation strategies within Canada's forest sector, (3) examine ES' trade-offs associated with CSF, and (4) identify implementation barriers and propose evidence-based pathways for solutions.

2.0 SFM AND CLIMATE CHANGE

Before the emergence of the CSF concept, SFM in Canada had already begun incorporating climate considerations through progressive practices, regulatory frameworks, third-party certification standards, and collaborative research efforts (Halofsky et al. 2018). Notable examples include federal assessments of forest vulnerability (Williamson et al. 2012) and guidance documents on climate adaptation in forestry (Edwards et al. 2012; Johnston et al. 2013). These foundational efforts have helped facilitate the incorporation of climate resilience and ecosystem health into Canadian forest management.

This section outlines the evolution of SFM in Canada, highlighting how its principles, policies, and implementation mechanisms have helped build a foundation for CSF. By reviewing these existing frameworks, we identify strategic components that can inform the development of effective, climate-resilient forest management pathways.

2.1 SFM: Origin and Application in Canada

SFM is designed to "maintain and enhance the long-term health of forest ecosystems for the benefit of all living things while providing environmental, economic, social, and cultural opportunities for present and future generations" (NRCan 2020). The core principles of SFM emphasize sustained productivity and health of forest stands, biodiversity conservation, regeneration following harvest, protection of soil and water resources, and well-being of communities. Fundamentally, SFM adopts a holistic, ecologically informed approach that seeks to balance economic, environmental, and social values across multiple spatial and temporal scales (Gauthier et al. 2023).

In the 1990s, a growing body of scientific evidence documenting biodiversity decline, along with heightened public concern over the potential implications of anthropogenic disturbances prompted a wave of international environmental action. Twelve major global conferences were convened to address these challenges. Among the most influential was the 1992 United Nations Conference on Environment and Development (UNCED), commonly referred to as the Earth Summit or Rio Summit. Several landmark frameworks and agreements emerged from this event, including (1) the Rio Declaration on Environment and Development, consisting of 27 principles to steer sustainable development efforts; (2) Agenda 21, an action plan targeting global sustainability by the year 2000; (3) the UN Framework Convention on Climate Change, which sought to curb greenhouse gas emissions and limit human interference with the climate system; (4) the Forest Principles, a set of 15 guidelines promoting the conservation and sustainable use of forests; and (5) the Convention on Biological Diversity.

Following the adoption of the Forest Principles, Canada became a founding member of the Montréal Process in 1994, joining 11 other countries committed to the development of criteria and indicators for monitoring the sustainability of temperate and boreal forests (Montréal Process 2015). Those five frameworks reinforced Canada's already rigorous forest policy and regulatory systems (NCASI 2025), which are widely recognized as being among the most robust globally (Gilani et al. 2020; NRCan 2023a). Federal, provincial, and territorial regulations, supplemented with voluntary best management practices and forest certification systems, form a multi-layered foundation for implementing sustainable forestry principles in Canada (NCASI 2021c).

To support national implementation, the Canadian Council of Forest Ministers (CCFM) developed a comprehensive criteria and indicators framework in 1995 to monitor progress on SFM goals. The framework includes seven criteria and 54 indicators, providing a systematic structure for assessment, adaptive management, and international collaboration (CCFM 1995; Table 2.1). Subsequent national reporting has continued to build on this foundation and served to demonstrate Canada's commitment to the goals set at UNCED (CCFM 1997; 2000). These criteria and indicators continue to inform SFM practices nationwide, and they are prominently featured annually in *The State of Canada's Forests Annual Report* (NRCan 2025d).

Current Status of Forest Harvesting in Canada

In 2021, Canada harvested approximately 0.3% (698,000 ha) of its 225 million ha of managed forest, with 88.5% (~200 million ha) under long-term forest management planning (NCASI 2021c).

Canada has very low levels of deforestation, which have decreased from 64,000 ha in 1990 to 51,000 ha in 2021, of which only 2% was attributable to forestry operations (NRCan 2021; 2022; 2024a).

Table 2.1. Criteria, sub-criteria and indicators outlined by the Montréal process to frame SFM. [*Source*: Adapted from Montréal Process (2015)]

Criterion	Criterion Intent	Sub-Criterion	Indicator
(1) Conservation of biological diversity	This criterion focuses on preserving the variety of life within forest ecosystems, encompassing ecosystem, species, and genetic diversity. Indicators include the area and percentage of forest by type, age class, and ownership, as well as measures of species diversity and the status of forest-dependent species.	1.1. Ecosystem diversity	1.1.a Area and percentage of forest by forest ecosystem type, successional stage, age class, and forest ownership or tenure 1.1.b Area and percentage of forest in protected areas by forest ecosystem type and by age class or successional stage 1.1.c Fragmentation of forests
		1.2. Species diversity	1.2.a Number of native forest-associated species 1.2.b Number and status of native forest-associated species at risk 1.2.c Status of on-site and off-site efforts focused on conservation of species diversity
		1.3. Genetic diversity	1.3.a Number and geographic distribution of forest-associated species at risk of losing genetic variation 1.3.b Population levels of selected representative forest-associated species to describe genetic diversity 1.3.c Status of on-site and off-site efforts focused on conservation of genetic diversity
(2) Maintenance of productive capacity of forest ecosystems	Ensuring forests can sustainably produce a range of goods and services is central to this criterion. Indicators assess the area of forest land available for wood production, the volume of wood and non-wood products harvested, and the sustainability of these harvest levels.		2.a Area and percentage of forest land and net area of forest land available for wood production 2.b Total growing stock and annual increment of both merchantable and non-merchantable tree species 2.c Area, percentage, and growing stock of plantations of native and exotic species 2.d Annual harvest of wood products by volume and as a percentage of net growth or sustained yield 2.e Annual harvest of non-wood forest products

(Continued on next page. See notes at end of table.)

Table 2.1 Continued

Criterion	Criterion Intent	Sub-Criterion	Indicator
(3) Maintenance of forest ecosystem health and vitality	This criterion addresses the resilience of forests to disturbances such as pests, diseases, and environmental stresses. Indicators evaluate the area and frequency of forest disturbances, the impact of pollutants, and the overall health and vitality of forest ecosystems.		3.a Area and percentage of forests affected by biotic processes and agents beyond reference conditions 3.b Area and percentage of forest affected by abiotic agents beyond reference conditions
(4) Conservation and maintenance of soil and water resources	Protecting soil and water quality within forested areas is the focus of this criterion. Indicators measure soil erosion rates, the impact of forestry activities on water quality and quantity, and the effectiveness of protective measures in place.	4.1. Protective function	4.1.a Area and percentage of forest designated for protection of soil or water resources
		4.2. Soil	4.2.a Proportion of forest management activities meeting best practices to protect soil resources 4.2.b Area and percentage of forest land with significant soil degradation
		4.3. Water	4.3.a Proportion of forest management activities meeting best practices to protect water resources 4.3.b Area and percentage of water bodies or stream length in forest areas with significant changes
(5) Maintenance of forest contribution to global carbon cycles	Recognizing forests' role in carbon sequestration, this criterion includes indicators that track forest biomass carbon stocks, changes in forest carbon pools, and the effects of forest management on carbon dynamics.		5.a Total forest ecosystem carbon pools and fluxes 5.b Total forest product carbon pools and fluxes 5.c Avoided fossil fuel carbon emissions by using forest biomass for energy

(Continued on next page. See notes at end of table.)

Table 2.1 Continued

Criterion	Criterion Intent	Sub-Criterion	Indicator
(6) Maintenance and enhancement of long-term multiple socio-economic benefits	This criterion emphasizes the social and economic benefits derived from forests. Indicators cover the production and consumption of forest products; employment and community needs; recreation and tourism; and the cultural, social, and spiritual values associated with forests.	6.1. Production and consumption	6.1.a Value and volume of wood and wood products production
			6.1.b Value of non-wood forest products produced or collected
			6.1.c Revenue from forest-based ecosystem services
			6.1.d Total and per capita consumption of wood and wood products
			6.1.e Total and per capita consumption of non-wood forest products
			6.1.f Value and volume of wood product exports and imports
			6.1.g Value of non-wood forest product exports and imports
			6.1.h Exports as a share of production and imports as a share of consumption
			6.1.i Recovery or recycling of forest products as a percentage of total consumption
		6.2. Investment in the forest sector	6.2.a Value of capital investment and annual expenditure in forest-related industries and services
			6.2.b Annual investment in forest-related research, extension, development, and education
		6.3. Employment and community needs	6.3.a Employment in the forest sector
			6.3.b Wage rates, income, and injury rates in forest employment
			6.3.c Resilience of forest-dependent communities
			6.3.d Area and percentage of forests used for subsistence
			6.3.e Distribution of revenues from forest management
		6.4. Recreation and tourism	6.4.a Area and percentage of forests managed for recreation and tourism
			6.4.b Distribution and type of recreational visits and facilities
		6.5. Cultural, social, and spiritual needs and values	6.5.a Area and percentage of forests managed for cultural, social, and spiritual values
			6.5.b Importance of forests to people

(Continued on next page. See notes at end of table.)

Table 2.1 Continued

Criterion	Criterion Intent	Sub-Criterion	Indicator
(7) Legal, institutional, and economic framework for forest conservation and sustainable management	This criterion examines the policies, laws, and institutions that support SFM. Indicators assess the existence and effectiveness of forest-related policies, the capacity of institutions to enforce laws and regulations, and the economic measures in place to promote sustainable practices.		7.1.a Legislation and policies for SFM 7.1.b Cross-sectoral policy coordination 7.2.a Economic strategies impacting forest sustainability 7.3.a Land and resource tenure security 7.3.b Enforcement of forest-related laws 7.4.a Resources supporting SFM 7.4.b Research and technology development for sustainable management 7.5.a Forest management partnerships 7.5.b Public participation and conflict resolution in forest decisions 7.5.c Monitoring, assessment, and reporting on SFM

Since the 1990s, SFM in the boreal forest has been guided by an understanding of natural disturbance regimes and the historical natural range of variation to preserve the ecological structure, function, and resilience of forests (Gauthier et al. 2023). However, as climate risks intensify, relying solely on past natural range of variation may result in forests being maladapted to future conditions (Messier et al. 2019; Millar et al. 2007). To reinforce forest resilience to future conditions, four adaptive strategic approaches have been proposed: passive management, resistance, resilience, and transition (Table 2.2). Briefly, the passive management represents a no-action approach (e.g., set-asides for protection). Enhancing resistance focuses on maintaining high-value forest conditions, such as habitat for endangered species. Strengthening resilience improves a forest's capacity to recover to a desired state following disturbance, particularly in areas where regeneration may fail due to repeated stress events (Kuuluvainen et al. 2018; Splawinski et al. 2019). Facilitating transition involves helping ecosystems adjust to future conditions, for instance, through assisted migration (Pedlar et al. 2012).

To support forest managers in identifying vulnerabilities and applying adaptation strategies, several guidelines and frameworks have been developed. Notably, adaptive management principles described by Gauthier et al. (2023) provide strategic direction. Additional resources, such as Edwards et al. (2015), Nagel et al. (2017), and Williamson et al. (2012), offer detailed frameworks for addressing climate-related risks in forest management planning, as discussed further in the following sections.

Table 2.2. Climate change adaptation strategies (passive, resistance, resilience, and transition) with associated definitions, goals, assumptions, and example management actions. [*Source*: Adopted from D'Amato et al. (2023)]

Strategy	Definition	Goal	Assumptions	Example Actions
Passive	No actions specific to climate change are taken	Allow a response to climate change without direct intervention	High risk in the mid to long term, low effort, good social acceptance (initially)	Harvest deferral on areas considered to have low vulnerability in the near term; forest reserve designation, particularly in areas expected to serve as climate refugia
Resistance	Improve the defence of a forest to change	Maintain relatively unchanged conditions over time	Low risk in the near term and moderate effort, high social acceptance	Density management and competition control to increase resource availability to crop trees; removal of nonnative species; reduction of fuel loading to minimize fire impacts; removal of low-vigour and high-risk individuals through stand improvement treatments
Resilience	Accommodate some change but remain within the natural range of variability	Allow some change; encourage a return to a condition within the natural range of variability	Medium risk in the midterm and medium effort, good social acceptance	Regeneration methods that encourage and maintain multi-cohort and mixed-species forest conditions (selection, irregular shelterwood); deliberate retention and maintenance of diverse structural attributes and functional traits
Transition	Accommodate change, allowing an adaptive response to new conditions	Actively facilitate the shift to a new condition to encourage adaptive responses	High risk in the near term and high effort, low social acceptance (initially)	Regeneration methods focused on encouraging genotypes and species expected to be adapted to future climate and disturbance regimes; generation of a wide range of environmental conditions in stands, ranging from high-resource, open areas to buffered reserve patches; can include enrichment planting as part of multi-aged systems or the establishment of novel plantations representing future-adapted individuals

2.2 Third-Party Forest Certification

Third-party certification has played a pivotal role in operationalizing SFM principles in Canada and is now increasingly aligned with CSF objectives. Canada's major certification systems, namely, the SFI, the FSC, and the Programme for the Endorsement of Forest Certification (PEFC), have long supported responsible forest management. In recent years, all three have revised their standards to incorporate climate adaptation and mitigation and social values, thereby moving closer to the aims of CSF (Appendix A).

Notably, in 2022, SFI introduced significant updates to its forest management standards by formally addressing climate change. These revisions introduced two critical new focus areas: CSF (Objective 9) and Fire Resilience and Awareness (Objective 10). These changes reflect a growing recognition of the need to address climate-related risks in forest management practices. FSC followed with its 2023 standard revision, which also incorporates climate adaptation and mitigation, alongside enhanced directives for integrating the social values of forests. These include stronger requirements for contributing to the well-being of local communities through forest management practices.

Technically, PEFC functions as a global alliance of national forest certification systems, promoting SFM through independent third-party certification. It is not a certification body itself. In Canada, PEFC has now assumed the Canadian Standards Association's (CSA) role by incorporating the technical content of the CSA Z809:16 (R2021)[2] standard into the new PEFC CAN ST 1001:2025. The previous CSA standard aligned with CCFM's SFM criteria and indicators, also incorporating Indigenous Peoples perspectives through the criterion on *Aboriginal*[3] *relations*. As such, PEFC Canada and SFI's Forest Management Standard now serve as the two PEFC-endorsed forest management standards in the country. Similar to CSA, PEFC Canada maintains alignment with the CCFM SFM framework and retains a dedicated criterion for Indigenous relations. It also explicitly includes requirements for addressing climate change in its latest documentation (PEFC Canada 2025).

3.0 CLIMATE-SMART FORESTRY

3.1 Definition

CSF is an integrated approach to SFM that explicitly combines climate adaptation, mitigation, and social objectives aimed at having forests remain resilient, productive, and capable of providing benefits to both people and ecosystems under changing climatic conditions. Although related concepts (e.g., Closer-to-Nature Forest Management[4]) share similar objectives, such as

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[2] CSA's SFM standard (CSA Z809:16[R2021]) has been withdrawn and replaced with PEFC Canada's standard (PEFC CAN ST 1001:2025) as of April 2025. However, current CSA certificates will remain valid during the transition period until April 18, 2026.

[3] The term *Aboriginal* is used when referring to CSA standards instead of *Indigenous Peoples* because this is the term used in CSA's National Standard of Canada Z809:2016, reaffirmed in 2021, withdrawn in April 2025.

[4] Closer-to-Nature is defined as "an overarching umbrella covering all approaches and terminologies which under the auspices of Sustainable Forest Management (SFM) support biodiversity, resilience and climate adaptation in managed forests and forested landscapes" (Larsen et al. 2022).

enhancing biodiversity, ecosystem resilience, and climate adaptation, CSF is distinguished by its structured, science-based methodology. This approach was co-developed by researchers and practitioners from 28 European countries (Bowditch et al. 2020; Tognetti et al. 2022).

A widely adopted definition, proposed by the European Cooperation in Science and Technology (COST) Action Group, describes CSF as follows:

> *Climate-Smart Forestry is sustainable adaptive forest management and governance to protect and enhance the potential of forests to adapt to, and mitigate climate change. The aim is to sustain ecosystem integrity and functions and to ensure the continuous delivery of ecosystem goods and services, while minimising the impact of climate-induced changes on mountain forests on well-being and nature's contribution to people.*
>
> Bowditch et al. (2020)

CSF is organized around three core components that frame strategic, operational, and logistical actions: adaptation, mitigation, and social values (Figure 3.1). Each of these components integrates economic, social, and environmental dimensions, fostering a comprehensive and systems-oriented approach to forest management in the face of climate change.

However, this definition, rooted in European forest contexts, has its limitations. It reflects a particular emphasis on mountain ecosystems and is shaped by regional ecological, economic, and governance structures (Tognetti et al. 2022). Consequently, the definition's global applicability may be constrained, and the relative weighting of each CSF component may differ depending on geography (Weatherall et al. 2022).

In Europe, CSF initiatives have predominantly focused on adaptation and mitigation, while the social dimension has often received less explicit attention (Weatherall et al. 2022). In Canada, social considerations are deeply embedded in federal and provincial policies and are integral to public engagement and formal consultations involving a wide range of stake-, rights-, and landholders (DOJC 2024; NCASI 2025; NRCan 2023b; 2023c; 2024c).

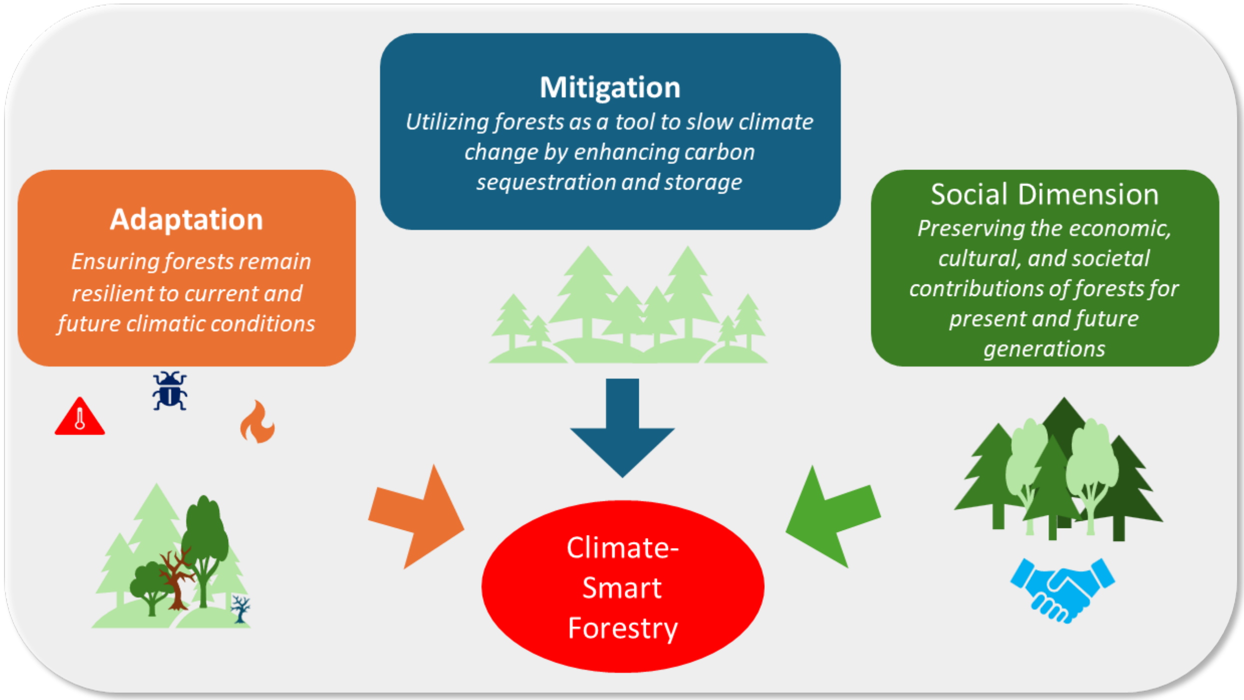


Figure 3.1. CSF encompasses three core components: adaptation, mitigation, and the social dimension

3.1.1 *Canadian Context*

Although interest in CSF has surged in recent years[5], inconsistent definitions have led to confusion and ambiguity regarding what actions or principles constitute CSF, particularly as many climate-focused forestry practices were already in place prior to the formalization of the concept (Cooper et al. 2023; Edwards et al. 2012; 2015; Swanston et al. 2016). To clarify how CSF is being conceptualized, particularly within the Canadian context, we conducted a literature review in 2025 to identify studies offering explicit definitions of CSF. This search yielded 17 studies that included some form of a CSF definition (Appendix B).

Our analysis revealed considerable variations in how these definitions were constructed, particularly in the extent and emphasis placed on each of the three core CSF components identified above. Notably, while nearly all studies (94%) referenced adaptation, only six (35%) included any mention of the social dimension. This omission is particularly significant in the Canadian context, where the social component is not just an optional consideration but a foundational aspect of forest management.

[5]As of September 2025, more than 1,700 papers were identified mentioning “Climate-Smart Forestry” via Google Scholar. Of these, slightly more than 1,400 have been published since 2021.

In Canada, the structure of forest land ownership[6], predominantly Crown land, and the corresponding regulatory frameworks, necessitate broad-based public engagement and consultation. Forest planning must account for the perspectives of stakeholders, rights-holders, and other involved parties within a forest management area (MCEC 2020). These consultations directly influence operational decisions in most provinces (NCASI 2021a; 2021b; Williamson et al. 2019), making the social dimension not only relevant but essential for effective and legitimate forest governance.

Thus, with these considerations in mind, and drawing from both the literature reviewed and the Canadian institutional context, we use the following working definition of CSF in this report:

An integrated approach to sustainable forest management that seeks to enhance the potential of forests to adapt to and mitigate climate change, while promoting the social and economic values of the forests in the form of rendered ecosystem services.

3.2 CSF Components

3.2.1 *Adaptation*

As the effects of climate change intensify, adapting forest management practices is essential to safeguard the long-term health of ecosystems, protection of infrastructure, resilience of forest-dependent communities, and broader human well-being (Council of Canadian Academies 2019; Halofsky et al. 2018). The adaptation component of CSF emphasizes strengthening forest resilience, both in terms of resistance to climate-induced stressors and the capacity to recover from them. Key climate-driven disturbances include prolonged droughts, increasingly frequent and intense wildfires, insect and disease outbreaks, and flooding events (Bowditch et al. 2020). Effective adaptation requires deploying a combination of strategic and operational actions that function across spatial and governance scales, from broader landscape and regional planning to stand-level interventions.

To support this effort, the recent National Council for Air and Stream Improvement, Inc. (NCASI) review mentioned above identified 29 primary adaptive strategies (PAS) categorized across 10 thematic focus areas. These strategies are drawn from the current scientific literature and designed to help forest managers enhance forest resistance, resilience, and transition to future climate change while also linking them to corresponding CCFM SFM criteria (NCASI 2023). Each PAS addresses a specific vulnerability and can be implemented at multiple planning levels (strategic, operational) and spatial scales (stand, landscape, region, etc.; Table 3.1).

Implementing any forest management strategy inherently involves a balance of benefits and challenges (and/or limitations). To mitigate the challenges, forest managers aim to align their objectives with local environmental conditions and community priorities. Also, when implementing PAS, managers must anticipate and navigate a range of possible challenges. For example, one key consideration is the forest's potential response to uncertain future climate

[6] In Canada, 91.4% (~317.2 million ha) are publicly owned. The constitutional ownership and management are predominantly held by individual provinces (~76.6%, ~265.8 million ha) and territorial governments (~12.9%, ~44.8 million ha) (NCASI 2021b).

conditions and environmental stressors, some of which may never materialize, while others could emerge rapidly. These uncertainties require flexible, forward-looking planning that considers a range of plausible scenarios to provide management action options, to remain effective under shifting ecological baselines.

Table 3.1. List of focus areas, each one containing relevant PAS, along with examples of options.
[*Source*: Adapted from NCASI (2023); Swanston et al. (2016)]

Focus Area	PAS	Examples
Ecological Function	Reduce Competition for Resources (e.g., water, nutrients, and light)	Perform pre-commercial thinning or selectively remove suppressed, damaged, or poor-quality trees to increase resource availability for the remaining trees
	Maintain or Restore Riparian Areas	Ensure that infrastructure investments do not interrupt conservation or riparian corridors
	Maintain or Restore Hydrology	Reassess river and stream peak flows, and link this information to design standards for bridges and roads
	Reduce Impact(s) on Soils and Nutrient Cycling	Maintain, decommission, and rehabilitate roads to minimize sediment runoff due to increased precipitation and melting of permafrost
	Restore or Maintain Fire-Adapted Ecosystems	Maintain under- and aboveground seed sources (seed banks on trees)
Biotic Disturbances	Maintain or Improve Forest Resistance to Pests and Pathogens	Adjust harvest schedules to harvest stands most vulnerable to insect outbreaks
	Prevent Introduction and Remove Existing Invasive Species	Control undesirable plant species that will become more competitive in a changed climate
	Manage Herbivory	Install physical barriers (e.g., fences, tree shelters) to prevent herbivory
Disturbance Risk & Severity	Diversify Forest Structure and Composition	Apply silvicultural techniques that maintain or increase species and structural diversity
	Reduce Fuel Loads and Establish Fuel Breaks in Fire-Prone Areas	Reduce fire hazard by implementing reduced-impact logging, e.g., through reduction in the size of felling gaps and fuel loads
	Regenerate Post-Disturbance	Preferentially use coastal provenances of species in areas likely to be affected by windstorms

(Continued on next page. See notes at end of table.)

Table 3.1 Continued

Focus Area	PAS	Examples
Habitat Refugia	Maintain (and improve when possible) Habitat for Species at Risk or Other Sensitive Species and/or Communities	Identify and protect functional groups and keystone species
	Establish and Maintain Forest Set-Asides	Protect climate refugia at multiple scales
Species & Forest Structural Diversity	Promote Diverse Forest Age Classes	Apply silvicultural techniques designed to maintain and increase diversity in species, age classes, and forest structure
	Maintain and Restore (when possible) Native Species	Increase the genetic diversity of trees used in plantations
	Retain Biological Legacies	Create artificial reserves or arboreta to preserve rare species
Ecosystem Redundancy	Manage Habitats Across a Range of Sites and Conditions	Ensure conservation corridors extend across environmental gradients
Connectivity & Fragmentation	Reduce Landscape Fragmentation	Establish landscape-level targets for structural or age-class measures, for landscape connectivity for species movement, and for passive or active measures to minimize the potential impacts of fire, insects, and disease
	Maintain and Create Habitat Corridors to Increase Connectivity	Ensure conservation corridors extend across environmental gradients
Genetic Diversity	Leverage Germplasm (e.g., seeds, plants) from Across Species' Range	Use germplasm mixtures with high levels of genetic variation when planting
	Favour Genotypes Adapted to Project Future Conditions	Match provenances of trees to new site conditions

(Continued on next page. See notes at end of table.)

Table 3.1 Continued

Focus Area	PAS	Examples
Managing Through Transition	Favour or Restore Native Species That Are Expected to Be Adapted to Future Conditions	Identify more suitable genotypes
	Establish or Encourage New Mixes of Native Species	Reduce the rotation age and follow with planting to speed the establishment of better-adapted forest types
	Guide Changes in Species Composition at Early Stages of Stand Development	For planted forests, establish indigenous, mixed-species stands, maximize natural genetic diversity, mimic the structural properties of the surrounding forests, and avoid direct replacement of native ecosystems
	Protect Future-Adapted Seedlings and Saplings	In natural forests, ensure large juvenile populations to promote high genetic variation
	Manage for Species and Genotypes with a Wide Climate Tolerance	Design tree plantations to have a diverse understory
	Introduce Species That Are Expected to Be Adapted to Future Conditions	Assist changes in the distribution of species by introducing them to new areas
	Translocate Species at Risk to Locations That Are Expected to Provide Habitat	Protect the most highly threatened species ex situ
Realign After Disturbance	Allow for Areas of Natural Regeneration to Test for Future-Adapted Species	Allow forests to regenerate naturally following disturbance; prefer natural regeneration wherever appropriate

Climate Vulnerability Assessment

To address uncertainty related to climate change effects on managed forests, managers can carry out a climate vulnerability assessment (CVA) that identifies the most significant threats to management objectives (Andrews-Key et al. 2021; 2025; Edwards et al. 2015; Halofsky et al. 2018; Lemprière et al. 2008; Nitschke et al. 2008; Williamson et al. 2012). The CVA framework offers a structured methodology for evaluating climate-related risks in forest management (Edwards et al. 2015; Williamson et al. 2012; Figure 3.2). The key purpose of each stage in the process along with practical steps are summarized in Appendix C.

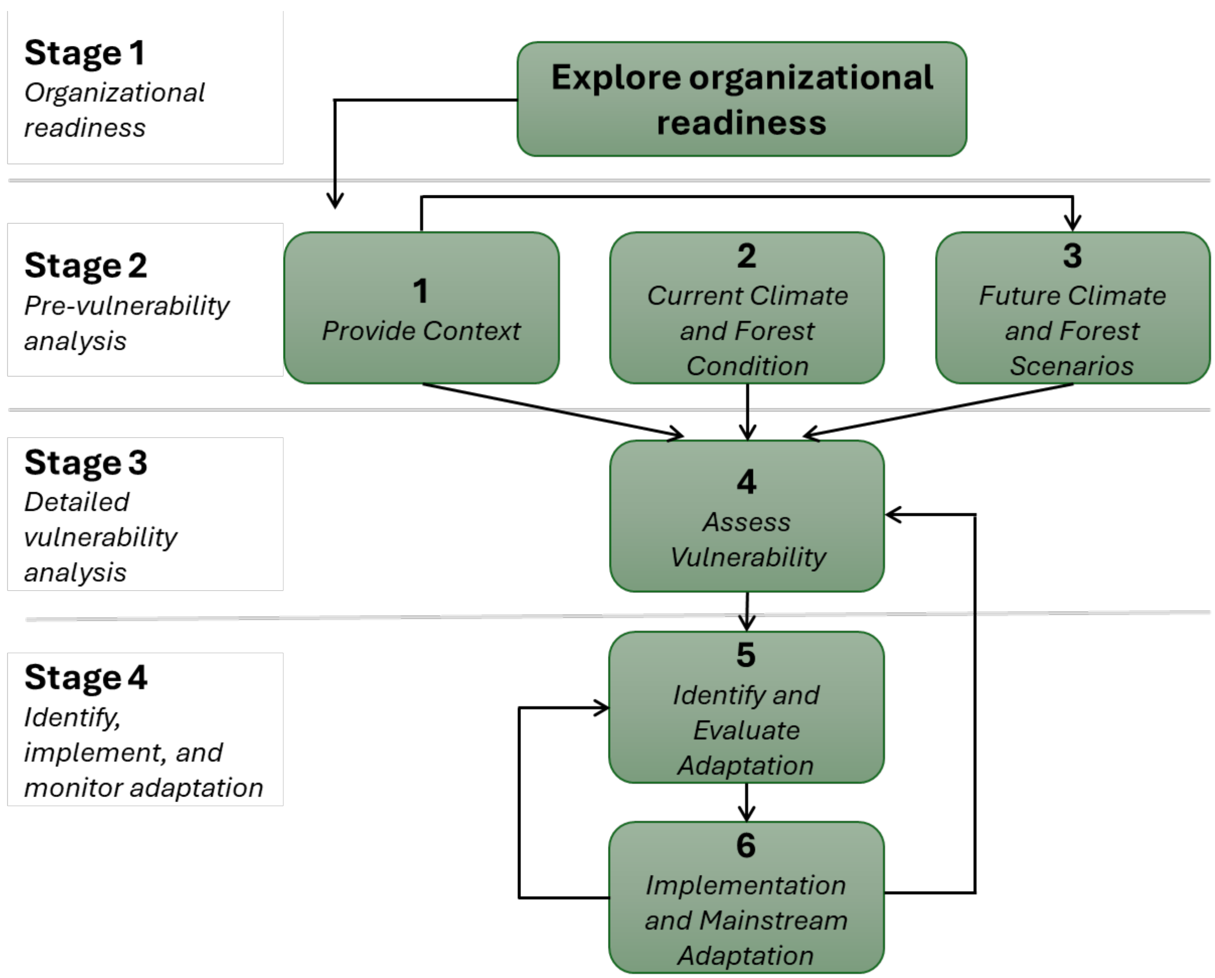


Figure 3.2. Four stages of adaptation to climate change in the context of SFM.
[*Source*: Adopted from Halofsky et al. (2018)]

Any proposed adaptation strategy must be evaluated for compliance with provincial and federal regulations (Government of British Columbia 2019; Williamson et al. 2012). Several resources are available to help guide practitioners in the development and implementation of adaptation strategies (NRCan 2025a). These include adaptation strategy workbooks and decision-support materials from Natural Resources Canada, CCFM, and others (Edwards et al. 2015; Halofsky et al. 2018; Swanston et al. 2016; Williamson et al. 2012). These tools assist managers from the initial stages of identifying vulnerabilities through to field-level tactic selection (see Figure 3.2). In addition, public engagement is essential, particularly in Canada, where a significant proportion of managed forests lies on public land. Consultations with Indigenous Peoples, local communities, and a wide range of stakeholders are a key step in developing an adaptation plan that considers a diversity of socioeconomic needs (MCEC 2020; Williamson et al. 2019).

Case Study 1: Taking the First Step: Vulnerability Assessment at Mistik Management Ltd.

The case of Mistik Management Ltd. represents one of the first documented examples in Canada of a forestry company systematically incorporating a climate change forest management plan on public land. As detailed by Andrews-Key et al. (2025), Mistik conducted a comprehensive CVA and integrated the findings into its 20-year forest management plan covering approximately 1.8 million ha of boreal forest in northwestern Saskatchewan. Mistik is co-owned by NorSask Forest Products LP and Domtar, with NorSask itself being a partnership of the Meadow Lake Tribal Council, which represents nine First Nations. NorSask operates Canada's largest First Nations–owned sawmill, and its revenues support various community development priorities, including infrastructure, employment, and social programs (NorSask Forest Products LP 2024).

Mistik initiated the CVA process during the renewal period for its long-term forest management plan, an ideal moment to incorporate climate considerations (Andrews-Key et al. 2025). This timing allowed the company to allocate internal resources to the initiative without disrupting core operations. Comparable opportunities have been leveraged by other companies in Canada, such as LP in Swan Valley (Andrews-Key et al. 2021).

A central feature of Mistik's approach was the integration of local and expert knowledge through structured workshops and active participation by the public advisory group, which included representatives from Meadow Lake Tribal Council. The CVA process followed the four-phase framework developed by CCFM (see Figure 3.2 and Appendix C). The results included the identification of key factors that will ultimately contribute to organizational readiness, documented existing and projected climate impacts, revealed knowledge gaps and uncertainties, and proposed adaptation strategies tailored to short- and long-term planning horizons.

Mistik's approach demonstrates how structured tools like the CCFM CVA framework can effectively integrate climate adaptation into operational forest planning. The success of the process was rooted in meaningful collaboration among land-, rights-, and stakeholders (Andrews-Key et al. 2025). This case demonstrates that advancing CSF does not necessarily require new staff or expensive infrastructure. Rather, the process can leverage existing planning mechanisms, participatory tools, and adaptive management frameworks already embedded in standard forestry operations. Through leadership, effective timing, and skilled facilitation, CSF principles can be mainstreamed into everyday practice.

Other Considerations for Adaptation: Diversity and Assisted Migration

Effective climate adaptation requires tailoring strategies to the timing, magnitude, and type of disturbance anticipated for a given forest region (Johnston et al. 2009). These strategies may target either short- or long-term climate challenges (Triviño et al. 2023). Long-term interventions are designed to enhance stand-level resilience before disturbances occur, thereby maintaining vital ecological functions and ecosystem services.

One widely recognized approach involves increasing tree species richness, age-class heterogeneity, and structural complexity, all of which are believed to enhance multifunctionality (Gamfeldt et al. 2013; Le Provost et al. 2022; Li et al. 2024; Messier et al. 2022) and buffer against climate-induced stresses and threats (Jactel et al. 2017). For example, recent studies have shown that stand productivity can increase in mixtures of broad-leaved and coniferous species through complementarity effects, particularly due to the faster initial growth of deciduous species relative to slower-growing conifers (Guignabert et al. 2024; Urgoiti et al. 2022; 2023). This positive diversity effect at the community level has been documented to increase over time, with net diversity effects remaining negative the first few years (three to six years) and becoming positive within the first decade (eight years onward) (Urgoiti et al. 2022).

However, the benefits of species diversity for resilience are not universal. For example, in Québec, a mixed stand of black spruce (*Picea mariana*) and aspen (*Populus tremuoides*) did not reduce the vulnerability to spruce budworm (Chavardès et al. 2021). In fact, black spruce in mixed stands showed a decreasing basal area during epidemic years, while pure stand values were slightly increasing (Chavardès et al. 2021). The authors concluded that a low proportion of hardwoods at the stand level may be insufficient to alter vulnerability, but broader landscape-level composition may still offer buffering effects (Campbell et al. 2008). Additionally, stands with only two to three species may not be diversified enough to confer functional resilience under a changing climate.

Proactive silviculture interventions can also address fire risk, such as increasing the use of fire-resistant species (e.g., broadleaf trees) in reforestation (Government of Canada 2023). In fire-prone regions, retaining cone-bearing trees during harvest can ensure a natural seed supply for post-fire regeneration, which may reduce reforestation costs and enhance resilience (Cyr et al. 2022).

One of the more transformative, yet debated, adaptation practices is assisted migration (AM). AM involves the deliberate translocation of tree species or genotypes to areas expected to become climatically suitable in the future. This anticipatory approach assumes the selected stock will persist under both current and projected climatic conditions (Pedlar et al. 2011). Many provinces have taken steps to evaluate and test seed transfer programs. For instance, British Columbia's Climate-Based Seed Transfer initiative, launched in 2012, aims to modernize seed selection practices by defining optimal transfer distances and ranges for maintaining stand productivity under future climate scenarios (O'Neill et al. 2017). This has enabled expanding planting zones for certain species, such as western larch (*Larix occidentalis*) (Klenk et al. 2015; Rehfeldt et al. 2010).

Additional evidence from eastern Canada supports the potential of AM. In a trial of eastern white pine (*Pinus strobus*) across Ontario and Québec, seedlings planted in a warmer site had 50% greater annual height growth than those in a colder site (Lu et al. 2024). Similarly, a study in southern Ontario showed that several oak species (*Quercus velutina, Q. rubra, Q. alba*) and black walnut (*Juglans nigra*) sourced from Pennsylvania and Tennessee performed comparably to local populations in early growth and survival, supporting cautious northward seed transfers (Pedlar et al. 2024). However, such outcomes can be delayed by priority effects, which refer to the competitive advantage of early-established species that may hinder the establishment of more climatically suitable species or provenances (Solarik et al. 2020).

Despite these early indicators of success, AM faces several challenges. For instance, the limited availability of suitable seed stock and the technical know-how to grow novel species for future climates have been identified as significant bottlenecks (C. M. Clark et al. 2023). Ethical debates also persist: some experts advocate for AM as necessary to maintain ES under rapid climate change, while others argue for letting ecosystems adapt on their own (Aubin et al. 2011). Risks associated with AM include establishment failure, genetic introgression, interspecific competition, and potential emergence of invasive species in novel environments (Aubin et al. 2011).

To help forest managers navigate these uncertainties and evaluate potential adaptation pathways, a broad range of open-access tools and data platforms are available that can help inform, guide, and validate adaptation approaches (NRCan 2025b; Torresan et al. 2021). These include predictive models, interactive decision-support tools, remote sensing applications, forest health databases, and monitoring systems capable of tracking changes in forest carbon, biodiversity, and disturbance regimes in near-real time (Table 3.2).

Table 3.2. Selected adaptation resources available from Natural Resources Canada. [*Source*: NRCan (2025a)]

Category	Resource (Link)	Brief Description
Climate & Environmental Monitoring	Climate Atlas of Canada	Interactive portal to explore climate impact, climate projections, and adaptation options across Canadian regions
	ClimateData.ca	High-resolution climate data mapping tools for visualizing changes in temperature, precipitation, and more
	Canadian Centre for Climate Services	Expert support, training, and tools to build climate resilience across sectors
	CFS Climate Modelling	Projections and historical datasets on temperature, precipitation, and other climate variables
	Power Analytics and Visualization for Climate Science (PAVICS)	A virtual lab for advanced climate data access and visualization
Forest Monitoring & Management	Canada's National Forest Inventory	National data on forest extent, condition, and trends that are used to inform policy and management
	Spatially Explicit Discrete Event Simulation Models - SpaDES	Modelling platform for simulating ecological dynamics, disturbances, and trade-offs at multiple scales
	Forest Insect and Disease Risk Maps	Spatial database showing areas at risk from pests and diseases affecting Canadian forests
Vulnerability & Risk Assessment	Canada's Plant Hardiness Zones	Maps indicating climatic suitability for plant species under current and projected conditions
	Forest Vulnerability Assessment Tool	Interactive platform assessing species' vulnerability to drought and other climate stressors.
	Vulnerability of Tree Species to Climate Change	Database summarizing species' climate sensitivity, adaptability, and exposure to risks
	Guidebook for Assessing Vulnerability and Mainstreaming Adaptation into Decision-Making (CCFM)	Workbook for assessing forest vulnerability and mainstreaming adaptation into SFM decisions

(Continued on next page. See notes at end of table.)

Table 3.2. Continued

Category	Resource (Link)	Brief Description
Adaptation Strategy & Implementation	SeedWhere	Tool to match seed sources with target planting sites based on current and future climate suitability
	Assisted Migration	Information on species relocation strategies to support resilience in future climate zones
	Database of Adaptation Options	Repository of adaptation actions derived from the scientific literature and case studies
	Forestry Adaptation Practitioners' Network	Online community for practitioners to exchange knowledge and best practices
	Map of Adaptation Actions	Case studies and examples of adaptation initiatives across sectors and regions in Canada
	Centre for Indigenous Environmental Resources	Supports Indigenous Peoples–led environmental stewardship and climate adaptation planning
Knowledge, Research, & Community Support	Knowledge Centre–CCFM	Portal to access reports on forest sector vulnerabilities, adaptation strategies, and research outputs
	Catalogue of Provenance Trials Applicable to Climate Change Adaptation Research	Summary of Canadian tree provenance trials supporting AM and climate-resilient planting
	National Tree Seed Centre	National repository preserving and distributing Canada's forest genetic resources
	Search the CFS Publication Database	Curated library of the latest publications from the Canadian Forest Service
	Indigenous Guardians	Funding and tools to support Indigenous Peoples–led environmental monitoring and land stewardship

3.2.2 *Mitigation*

Mitigation in the context of CSF refers to strategies aimed at reducing net greenhouse gas (GHG) emissions through forest management and the sustainable use of forest products. These strategies aim to optimize carbon sequestration and long-term storage in both forest ecosystems and wood products, while minimizing emissions from forestry operations.

Forest Carbon

Forests store a significant portion of the world's carbon (C), making them vital to global climate change mitigation efforts (Harris et al. 2021). Through photosynthesis, trees absorb atmospheric carbon dioxide (CO_2) and convert it into sugars, fueling metabolic processes and contributing to structural biomass. These compounds accumulate in branches, trunks, leaves, and roots, and eventually the soil, forming both above- and belowground carbon pools. The total biomass produced is called gross primary productivity. After accounting for autotrophic respiration (R_a), the remaining carbon constitutes net primary production. As trees grow, carbon is gradually stored in biomass and soil, contributing to long-term carbon storage (Figure 3.3).

Forest carbon dynamics can be quantified by calculating net ecosystem production, the difference between net primary production and the total respiration of plants and decomposers (Landsberg et al. 1997). A positive net ecosystem production indicates a forest acts as a carbon "sink"; a negative net ecosystem production implies it functions as a carbon "source." Factors such as species composition, age structure, climate, and disturbance events (e.g., wildfire, harvest, pests) can influence this balance.

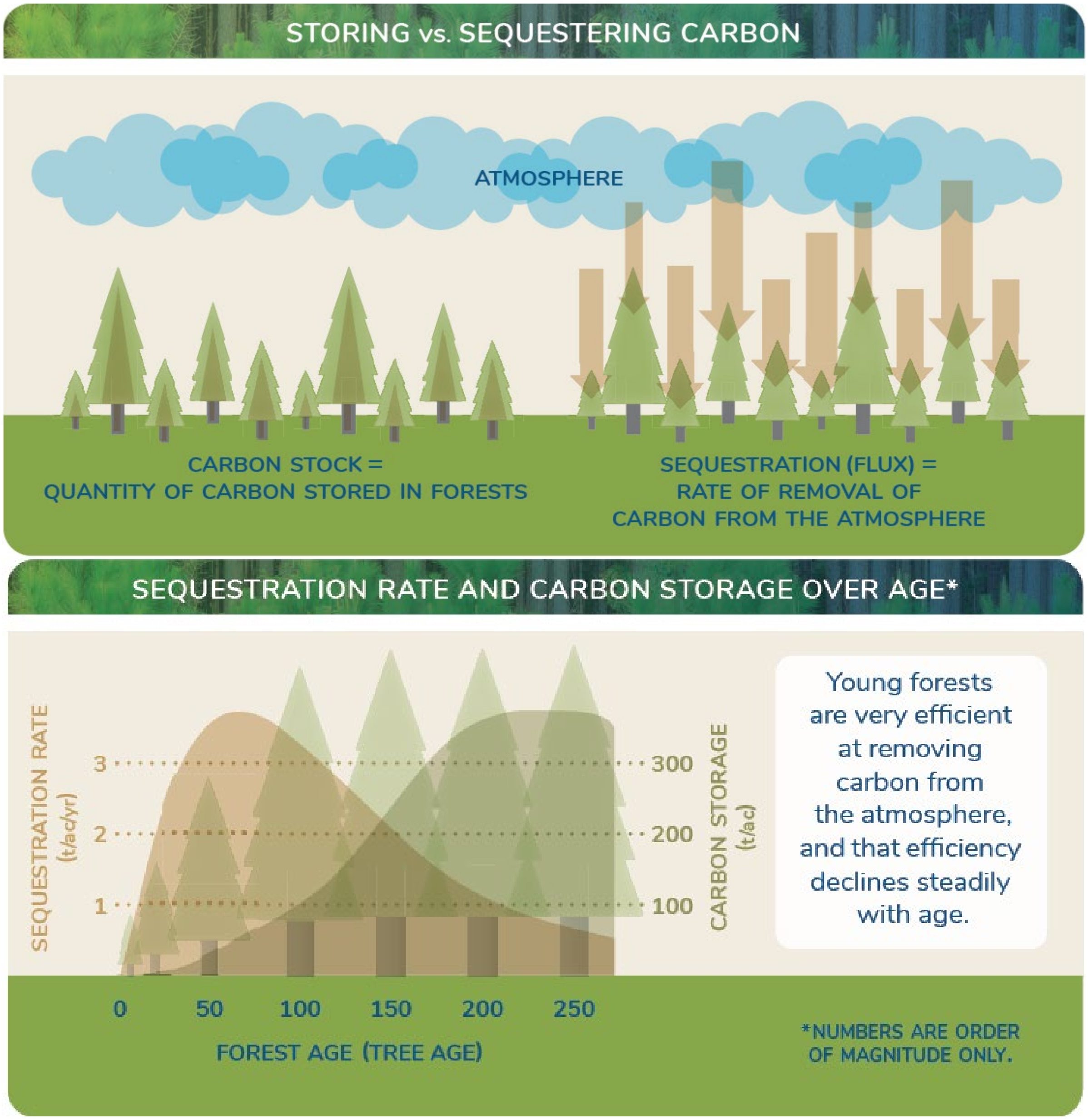


Figure 3.3. Forest carbon storage vs. forest sequestration.
[*Source*: *Adopted* from NCASI (2021a)]

Carbon fluxes can be modeled through both sequestration and storage; however, the two concepts are not synonymous. Sequestration represents the rate of carbon uptake from the atmosphere, whereas carbon storage represents the accumulated carbon pool in soils, biomass, and forest products (NCASI 2020b). Younger forests often exhibit higher rates of sequestration due to rapid growth but store less total carbon than older forests (Landsberg et al. 1997; Loehle et al. 2019; Odum 1969) (see Figure 3.3). As forests mature, growth slows and mortality reduces net sequestration, sometimes close to zero (Diaz et al. 2018; Gray et al. 2016). Consequently, forest management plays a crucial role in sustaining high net sequestration rates, often achieved near the culmination of mean annual increment, thereby supporting climate mitigation objectives (M. R. Allen et al. 2009; Intergovernmental Panel on Climate Change 2013; Miner et al. 2014; NCASI 2020b; US Global Change Research Program 2017).

Models that mainly focus on forest carbon stocks risk overestimating climate benefits, as they may overlook substitution effects (where wood replaces higher-emission materials such as concrete or steel [Leskinen et al. 2018]) and leakage (where harvest is displaced to other regions [Gan et al. 2007; Wear et al. 2004]). Also, harvested wood storage is sometimes discounted as impermanent, yet forest carbon itself is subject to permanence risks from fire, drought, pests, and extreme weather events, all of which are expected to worsen under climate change (Anderegg et al. 2020).

Recent disturbances, particularly wildfires, have already had a pronounced impact on the carbon balance of Canada's forests. For example, in 2023 alone, approximately 15 million ha burned across Canada (Jain et al. 2024), with some top-down[7] approaches (i.e., CO measurements from fire plumes) estimating carbon emissions reaching 647 Tg C, representing a more than five-fold increase in annual emissions from wildfire recorded (2010–2022) (Byrne et al. 2024). Although top-down assessments generally indicate that Canadian ecosystems act as a net carbon sink when considering all land within the Canadian carbon budget (Byrne et al. 2023), some experts argue that intensified fires have reduced Canada's carbon uptake potential (Wang et al. 2021).

Taken together, these findings highlight the growing risk of forests shifting from net carbon sinks to net carbon sources, emphasizing the need for targeted mitigation strategies.

Carbon Measurement

Historically, climate change mitigation was not systematically integrated into Canadian forest management planning. However, mounting pressures to reduce national GHG emissions and advances in forest carbon science have driven the development of resources, tools, and protocols for incorporating carbon objectives into management strategies.

Notable examples include the following:

[Models]

- The Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3) simulates carbon dynamics in biomass, litter, deadwood, and soil using forest inventory and management data (Government of Canada 2025g).
- The Generic Carbon Budget Model (GCBM) expands on CBM-CFS3 by including modules to track carbon in moss and peat pools (Government of Canada 2025d). Additionally, the moss carbon extension and module (MOSS-C) improve the

[7] Top-down approach (fire carbon emissions): A method that refines bottom-up fire emission estimates by aligning them with observed atmospheric concentrations of trace gases in fire plumes. This involves scaling model outputs to match satellite-based measurements, such as CO data from instruments like TROPOMI, thereby improving the accuracy of GHG emission estimates (Byrne et al. 2024).

ability of these models to estimate carbon stored in organic "peaty" soils in coniferous forests, especially those dominated by black spruce (Government of Canada 2025e). Another module specifically targets the carbon balance of 11 peatland categories (CaMP), including forested treed swamps, bogs, and fens (Government of Canada 2025h).

[Monitoring]

- The National Forest Carbon Monitoring, Accounting, and Reporting System (NFCMARS) uses inventory data, remote sensing, and forest modelling to track emissions and removals in managed forests over decades (Government of Canada 2025a).

[Social]

- Incorporating Indigenous knowledge alongside Western science is increasingly recognized as essential for fostering SFM practices that effectively mitigate climate change. Canada has committed $500 million from the 2 Billion Trees program to support Indigenous Peoples–led reforestation projects (Government of Canada 2024a; 2024b), such as Nekoté Limited Partnership's plan to plant 20.8 million trees by 2031 in Northern Manitoba (Government of Canada 2024b).
- Programs like Nature Smart Climate Solutions and Indigenous Forestry Initiative (IFI) further enable inclusive, climate-resilient practices (NRCan 2025b).

Strategies

Forestry-based mitigation strategies play a critical role in reducing GHG emissions within the sector. Practices such as minimizing disturbance during harvesting, narrowing the width of forest roads, and accelerating post-harvest reforestation can contribute to lowering emissions (Government of Canada 2025c). In contrast, reducing harvesting volumes alone would likely have a limited effect on forest carbon emissions in Canada, for several reasons. About 0.2% of the managed forest area is harvested annually (NRCan 2025d), and approximately 60% of the harvested area is re-established through planting and seeding within a few years, while the remaining is left to regenerate naturally (NCASI 2024). This rapid regeneration helps avoid potential long-term delays in forest recovery and associated losses in carbon sequestration capacity, which may occur if harvesting is poorly timed with natural regeneration processes (NCASI 2024; Solarik et al. 2010). Additionally, a significant portion of the carbon removed during harvesting is retained in long-lived forest products such as lumber and engineered wood products, helping to mitigate emissions over the product's life cycle (Skog 2008; Taylor et al. 2023; Zhao et al. 2022). Emissions from forestry operations are relatively minor when compared to those from natural disturbances, such as wildfires and insect outbreaks. For instance, in 2022, anthropogenic activities in Canada's managed forests emitted approximately 21 Mt CO_2e, while natural disturbances contributed 93 Mt CO_2e (NRCan 2025d). On average, the area affected annually by wildfire is 2.5 times larger than the harvested area, with wildfires releasing substantial carbon emissions through smoke (Government of Canada 2025c). Despite significant investments, amounting to billions of dollars each year, by governments and industry in fire-suppression efforts, not all fires can or should be extinguished, as they could play an important role in maintaining forest health and regeneration processes (Government of Canada 2025f).

Another important consideration in forest-based climate mitigation is the substitution effect of forest products. Forests provide the raw materials for a broad range of essential goods, including lumber, paper, and cardboard. If forest harvesting in Canada were curtailed, the global demand for these products would persist, potentially shifting production to regions that do not follow SFM practices. This shift could inadvertently lead to increased GHG emissions and biodiversity loss elsewhere.

Furthermore, substituting forest products with more carbon-intensive materials such as concrete, steel, and plastics can result in higher life cycle emissions (Mofolasayo 2022; Schenk et al. 2022). A recent life cycle assessment (LCA) in Alberta illustrated this trade-off: constructing a house with concrete columns, beams, and walls clad in brick generated 55,400 kg CO_2e, whereas using glue-laminated and cross-laminated timber walls with spruce siding produced 16,200 kg CO_2 e, a 242% increase in emissions compared to using concrete-based materials (Mofolasayo 2022). A broader global review of over 100 case studies supports this finding, indicating that timber buildings have, on average, 28% lower embodied energy[8] per square meter than those built with concrete (Schenk et al. 2022). These results reinforce the need to maintain sustainable harvesting practices in Canada to support both climate goals and material demands.

In addition to the substitution benefits, enhancing forest carbon sinks through afforestation and reforestation is another available mitigation strategy. These practices increase carbon uptake and storage in both biomass and soils (Zhang et al. 2023), while SFM can prolong the persistence of carbon stocks (Ontl et al. 2020). Though afforestation in Canada occurs on a small scale (~ 9,000 ha annually), it is estimated to remove 0.2 to 1 million tonnes of CO_2 annually, with sequestration benefits accumulating over time as forests mature (NRCan 2024b; 2025c).

In this context, the mitigation component of CSF emphasizes optimizing forest management to maximize carbon storage across three primary pools: aboveground (trees), belowground (soils), and forest products. This includes strategies aimed at enhancing carbon uptake and reducing emissions, particularly from disturbances (Table 3.3).

[8] *Embodied energy*: the energy that is consumed during the production stage of the building, covering the construction materials and construction energy involved (Schenk et al. 2022).

Table 3.3. Non-exhaustive list of forest management and planning strategies that support climate change mitigation.

Category	Strategy	Description	Reference
Forest Establishment & Retention	Afforestation	Establishing forests on previously non-forested land to create new carbon sinks	(Ménard et al. 2023)
	Reforestation (Post-Harvest)	Replanting forests following logging or disturbance to accelerate the transition from carbon source to sink	(Ménard et al. 2023)
Forest Management & Operations	Improved Harvesting Practices	Using low-impact logging techniques (e.g., narrower roads, directional felling) to reduce immediate carbon loss	(Brooks 2025)
	Extended Rotation and Retention	Increasing harvest intervals and retaining forest patches to maintain on-site carbon stocks	(Gauthier et al. 2009)
	Enhanced Forest Growth	Boosting productivity through species selection, breeding, and fertilization	(Devisscher et al. 2021)
Disturbance Management	Wildfire Management	Reducing fuel, using prescribed burns and suppression to limit carbon losses from fires	(Williamson et al. 2019)
	Pest and Disease Management	Controlling outbreaks (e.g., mountain pine beetle, spruce budworm) to reduce mortality and emissions	(Anderegg et al. 2020)
Product & Substitution Strategies	Harvested Wood Products and Substitution	Using wood in long-lived products and substituting for more carbon-intensive materials	(Loehle 2025)
	Bioenergy Utilization	Converting low-grade wood or residues into renewable bioenergy	(Loehle 2025)

Trade-offs, Uncertainty, and Adaptive Management. Despite their mitigation potential, forest-based strategies come with inherent trade-offs due to the inherent uncertainties associated with climate change (Bellassen et al. 2014). Climate unpredictability, increasing disturbance frequency, forest dieback, and changing hydrological patterns can all diminish the carbon sink capacity of forests (Anderegg et al. 2020). This reinforces the need for adaptive management, which allows strategies to evolve as conditions change (Shephard et al. 2023).

While managed forests can offer higher carbon sequestration potential (Noormets et al. 2015), the effectiveness of strategies is highly context dependent. For instance, long-term simulation studies (2020–2100) in Canada's boreal and northern temperate forests show diverging outcomes depending on forest type and management (Moreau et al. 2022). More specifically, it was found that reducing harvest levels by 11%–50% compared to business as usual significantly increased carbon mitigation. The emissions from clearcutting in that context could not be offset by wood product storage or substitution effects. In contrast, in these temperate forests, partial cutting and moderate harvest intensification (6.3%–13.9%) improved mitigation outcomes (−10 to −15 t CO_2e ha^{-1}). Notably, the temperate forests under no management were projected to become net carbon sources over time (Moreau et al. 2022). These results underscore the importance of tailoring mitigation strategies to local ecological conditions and socioeconomic factors.

Challenges in Afforestation and Reforestation. Reforestation and afforestation can significantly enhance carbon storage (Magnus et al. 2021; Ménard et al. 2023; Zhang et al. 2023). However, implementation often depends on the availability of suitable land and the sustained engagement of stakeholders to balance potential benefits with associated trade-offs (Dsouza et al. 2025). Key challenges include issues related to land tenure, risks of land-use change (Ménard et al. 2023), fluctuating market values (Dominy et al. 2010), and both economic and operational barriers. Long-term funding commitments are also essential to support these initiatives over the decades required to see meaningful carbon benefits (Magnus et al. 2021; Ménard et al. 2023).

Recent evaluations suggest that implementing these approaches on unproductive or marginal lands can contribute meaningfully to carbon sequestration goals, especially when they are integrated as part of a larger portfolio of mitigation strategies (Magnus et al. 2021; Ménard et al. 2023). When applied at appropriate scales and maintained over medium to long timescales (50–80 years), reforestation and afforestation can provide substantial and durable climate benefits.

3.2.3 *Social Dimension*

The social dimension component of CSF encompasses all actions that deliver both tangible and intangible benefits for human communities. These benefits may be economic, cultural, spiritual, scientific, or recreational in nature. Compared to the adaptation and mitigation pillars of CSF, the social component has received the least attention in the academic and peer-reviewed literature (Shephard et al. 2023). Often, it is overlooked entirely or vaguely referenced as "nature's contribution to people's well-being" (see Appendix B). However, integrating a strong social dimension into CSF can enhance forest-based climate solutions while promoting community well-being by aligning local and global ecosystem service delivery with the needs, values, and aspirations of the people affected (Tognetti et al. 2022).

This social component is particularly critical in the Canadian context, where most forested land is publicly owned and managed. Inclusive, transparent, and sustainable decision-making requires meaningful participation from a diverse array of stake-, rights-, and landholders (MCEC 2020). Federal and provincial regulations mandate that forest managers preserve a broad range of ecosystem services, such as maintaining water quality, biodiversity, and cultural values, across managed landscapes. However, a distinct and vital aspect of the Canadian forest governance model is its evolving relationship with Indigenous Peoples. Many Indigenous and rural communities are especially vulnerable to climate impacts, making it essential that CSF approaches address social equity and build resilience within these communities (Reyes-García et al. 2024).

Canada's approach to SFM already integrates a robust social dimension, which is embedded in the Montréal Process Criteria and Indicators (see Table 2.1) and reinforced through third-party forest certification systems (see Appendix A). These standards explicitly emphasize the engagement of Indigenous Peoples and local communities. Collaborative forest management frameworks also aim to respect Indigenous knowledge and rights systems, ensuring they are reflected meaningfully in forest planning and decision-making processes (Interfor 2025; West Fraser 2025).

The federal government supports these goals through a variety of initiatives, such as the Indigenous Initiatives Program and Indigenous Natural Resources Partnerships programs (NRCan 2025b), which promote economic development and climate resilience in Indigenous communities through forest-based opportunities. In addition, many forestry companies now align their policies with the United Nations Declaration on the Rights of Indigenous Peoples (NRCan 2024c) and the Truth and Reconciliation Commission of Canada's Calls to Action (TRCC 2015). These commitments emphasize principles as free, prior, and informed consent; continuous engagement; and building lasting, trust-based relationships with communities through collaborative initiatives and co-developed management strategies.

Key Components of Canada's Social Forestry Values

Notable social values within the CSF framework can be broadly categorized into four, often overlapping components:

1. **Indigenous Engagement and Leadership**

   Indigenous relations are an integral component of forestry companies' policies and CSF, given their deep-rooted connection to forested lands. Over 70% of First Nations are situated near or within forested areas (NAFA 2020), making their leadership, rights, and knowledge systems critical to climate-resilient forest management.

   The Indigenous Forestry Initiative supports Indigenous leadership in forest governance by integrating traditional ecological knowledge with modern forestry practices to enhance both resilience and sustainability. One example of a co-management model is the Joint Development Agreement signed by Williams Lake First Nation and West Fraser, which merges their local tenure volumes into a single First Nations Woodland License under the Nation's management (Wood & Panel USA 2024). Another example is Mistik Management Ltd., a partnership jointly owned by nine Indigenous Nations (via NorSask Forest Products) and Domtar (see Case Study 1 above).

2. **Community Engagement and Social License**

   Community engagement is fundamental for securing a social license to operate, especially in rural and forest-dependent regions where changes in forest management can directly impact livelihoods and well-being. Early and consistent public involvement promotes transparency, responsiveness, and alignment with local values (Andrews-Key et al. 2025).

In support of reconciliation, Wong et al. (2020) outlined 10 Calls to Action to Natural Scientists to guide respectful engagement with Indigenous communities (Table 3.4). Even prior to these calls, Canada has been one of the most advanced countries in terms of integrating Indigenous knowledge into forest planning thanks to high levels of Indigenous participation[9] (Cheveau et al. 2008; Karjala et al. 2003; 2004; McGregor 2002; Natcher et al. 2002; 2005; Robinson et al. 1997). An example of meaningful engagement is the partnership between Weyerhaeuser and Horse Lake First Nation and the Aseniwuche Winewak Nation around Grande Prairie, Alberta. Weyerhaeuser supports these communities with funding and in-kind resources to identify, validate, and document cultural and traditional forest knowledge that supports these objectives (Weyerhaeuser 2025).

[9] Cheveau et al. (2008) used the Berkes (1994) scale of co-management. This is a framework for assessing levels of participation and power sharing between government or industry managers and local or Indigenous communities in natural resource management. It has seven levels: (1) informing, (2) consultation, (3) cooperation, (4) communication, (5) advisory committees, (6) management boards, (7) partnership of equals/community control.

Table 3.4. Ten calls to action to natural scientists working in Canada.
[*Source*: Adapted from Wong et al. (2020)]

Call to Action	Main Objective
Call 1: Understand the socio-political landscape around their research sites.	Natural scientists should learn who has jurisdiction or interests in their research sites, including local Indigenous governments and ethics guidelines. They should consult communities to obtain free, prior, and informed consent, recognizing Indigenous Peoples rights to self-determination.
Call 2: Recognize that generating knowledge about the land is a goal shared with Indigenous Peoples and seek meaningful relationships and possible collaboration for better outcomes for all involved.	Scientists and Indigenous Peoples both aim to understand the land. Building meaningful relationships and exploring early collaboration can lead to better, more reciprocal outcomes for both science and communities.
Call 3: Enable knowledge sharing and knowledge co-production.	Move beyond inaccessible academic publications. Make research results accessible (e.g., translations, youth-friendly media), hold workshops, repatriate data. Collaborate with communities to co-produce new knowledge, respecting Indigenous knowledge protocols.
Call 4: Seek advice from Elders for respectful ways of handling animals.	Animal research must respect local Indigenous customs and values about stewardship and animal ethics. Researchers should consult Elders and communities to adapt methods accordingly, recognizing local protocols and beliefs.
Call 5: Provide meaningful opportunities for Indigenous community members, particularly youth, to experience and participate in science.	Engage and hire Indigenous youth as field technicians, offer training and experiences that link science with cultural revitalization, and build capacity to help address gaps in science literacy and representation.

(Continued on next page. See notes at end of table.)

Table 3.4. Continued

Call to Action	Main Objective
Call 6: To decolonize the landscape, incorporate Indigenous place names as permitted.	Using Indigenous place names acknowledges long histories and deep cultural meanings of places, helps keep languages alive, and respects Indigenous Peoples knowledge about the landscape. Always seek permission and use names in proper context.
Call 7: Take a course on Indigenous Peoples history and rights.	Scientists and their students should be required to learn about Indigenous histories, residential schools, treaties, the United Nations Declaration on the Rights of Indigenous Peoples, and local governance to address widespread ignorance about Indigenous Peoples rights and contexts of research.
Call 8: Encourage funding bodies to change approaches to funding.	Funding bodies should prioritize projects that respond to Indigenous communities' needs, simplify application and reporting processes for Indigenous organizations, value Indigenous knowledge in assessing expertise, and involve Indigenous reviewers.
Call 9: Remind editors of all scientific journals to recognize that publication of research on Indigenous knowledge and cultural resources requires review and permission from the respective Indigenous communities.	Scientific journals should adopt guidelines requiring community review of any work involving Indigenous knowledge or cultural resources, respecting ownership and preventing harmful or exploitative publication practices.
Call 10: Encourage natural scientists and post-secondary research institutions to develop a new vision for conducting natural science: fundamentally mainstreaming reconciliation in all aspects of the scientific endeavor, from formulation to completion.	All scientists and institutions should embed reconciliation in all stages of research, from planning to publication. Go beyond minimum consultation requirements to foster relationships, reciprocity, and mutual benefit.

3. **Economic Benefits and Community Development**
Forestry contributes significantly to rural areas and Indigenous communities by providing employment, income, and business opportunities. In 2023, 199,345 Canadians were employed in the forest sector (NRCan 2025d), with19% identified as women, 12% as visible minorities, and 6% as Indigenous. Programs (e.g., the Indigenous Forestry Initiative, Free to Grow in Forestry, among others) that address local development priorities and socio-economic disparities can strengthen the effectiveness of climate mitigation and adaptation (Montréal Process 2015). Many companies have formalized their approach to building and maintaining long-lasting relationships with Indigenous Peoples. This is common practice among Canadian forestry companies, which incorporate Indigenous knowledge into forest practices, create business partnerships, or return economic value to local communities, among other objectives (NRCan 2024c). For example, West Fraser reports that 8.3% of its Canadian workforce is Indigenous and engages with more than 80 communities across its land base (West Fraser 2025). Tolko has signed the Minerva Foundation Pledge to promote women's participation across all company roles (Tolko 2025). Revenue-sharing arrangements and Indigenous business partnerships, such as Mistik's co-ownership model, are further examples of inclusive economic development.

4. **Education and Capacity Building**
Capacity-building initiatives are key to advancing CSF. Programs like the Outland Youth Employment Program offer Indigenous youth forestry training and hands-on experience (Weyerhaeuser 2025). The Project Learning Tree, a program of SFI, offers environmental education, forest literacy, and career development opportunities (PLT Canada 2025). Opportunities for post-secondary scholarships funded by forest companies to support Indigenous leadership in education also exist (Domtar 2025).
The industry also has a long-standing dedication to funding science-based research and innovation. Many companies meet certification standards such as SFI's objective 12 (Forestry Research, Science and Technology[10]) through internal projects and partnerships. Examples include collaborations with the Alberta Regional Caribou Knowledge Partnership (West Fraser 2025; Weyerhaeuser 2025), and national projects like DIVERSE or Silva 21, which are multi-university and partner initiatives to develop tools, science, and collaboration for improving forest resilience to disturbances.

Through these interconnected efforts, SFM in Canada illustrates how forestry can advance social equity, resilience, and community well-being within the CSF framework. SFM in Canada demonstrates how CSF can serve both ecological and social objectives. The Canadian model emphasizes equity, inclusivity, and local relevance, aiming to ensure forest benefits are shared

[10] SFI's Objective 12. "Forestry Research, Science and Technology: To invest in research, science and technology, upon which sustainable forest management decisions are based. Performance Measure 12.1. Certified Organizations shall individually and/or through cooperative efforts involving SFI Implementation Committees, associations or other partners provide in-kind support or funding for forest research to improve sustainable management of forest resources, and the environmental benefits and performance of forest products."

broadly and that Indigenous and local voices remain central to shaping forest futures. These priorities align with global trends; for instance, Hallberg-Sramek et al. (2022) identified 39 social indicators for CSF in Sweden, including local knowledge, value chains, and participatory governance (Appendix D), reinforcing the importance of the social dimension of CSF worldwide (Andrews-Key et al. 2025).

4.0 CSF APPLICATION IN CANADA

4.1 Extent of CSF Research and Application

The principles of adaptation, mitigation, and social responsibility are actively embedded in Canada's forest management systems, largely through the implementation of the SFM framework. While many of these practices closely align with CSF, they have rarely been explicitly identified as such (Edwards et al. 2015; NCASI 2023; Swanston et al. 2016). Recent overviews of forest adaptation and mitigation initiatives indicate widespread activity across Canada, though direct references to CSF remain limited (Antwi et al. 2024a; Williamson et al. 2019). Notably, most documented actions originate from governmental institutions.

Canada formally acknowledged climate change as a priority in forest policy in 2008, when the CCFM released a vision statement highlighting climate change impacts on forests (CCFM 2008). That same year, CCFM launched the Climate Change Task Force, which advanced CSF-aligned priorities across three core phases (Williamson et al. 2019):

1. *Assessing the vulnerability* of Canada's tree species to climate change (Johnston et al. 2009);
2. *Developing decision-support tools and technical resources* for forest managers (Edwards et al. 2015);
3. *Promoting inter-jurisdictional dialogue* to embed climate change considerations into SFM policies and definitions (Williamson et al. 2019).

In parallel with Climate Change Task Force efforts, many provinces and territories have independently adopted various adaptation and mitigation strategies (Appendix E). Six priority areas for climate adaptation in forest management have been identified (Williamson et al. 2019):

1. *Adapting to Wildfire Risk:* integrating climate projections into fire assessments and employing adaptive fire strategies (e.g., cultural or prescribed burning, FireSmart™ programs);
2. *Modernizing Pest Management:* addressing pest and pathogen outbreaks increasingly exacerbated by warming trends;
3. *Preventing Maladaptation Risk:* integrating climate considerations into seed transfer decisions, AM trials, and species selection;
4. *Reducing Windthrow Risk:* modifying stand structure and silviculture practices to improve stability;
5. *Operational Resilience:* enhancing the ability of forest businesses to withstand climate-induced economic disruptions;

6. *Integrating Climate into Planning:* mainstreaming climate adaptation into forest assessment, monitoring frameworks, and long-term planning.

While these strategies have been incorporated in various provinces, implementation remains inconsistent. According to Antwi et al. (2024a), many initiatives are still in the pilot or trial stages. Their review of literature from 1997 to 2021 found that most documents reporting results on these initiatives concentrated in western provinces, primarily British Columbia and Alberta, and often focused on a limited set of practices, including climate-based seed transfer and fuel management (Table 4.1). Enhanced silviculture and reforestation for carbon sequestration and ecosystem resilience were also represented, though comprehensive, long-term data across large geographical scales remain scarce (Antwi et al. 2024a). Moreover, industry-led CSF principles are under-represented in the peer-reviewed literature (Andrews-Key et al. 2021; 2025), despite being present in the sustainability and climate strategies of major forest companies (e.g., Mosaic 2024; Tolko 2025; West Fraser 2025; Weyerhaeuser 2025).

One area in which CSF-aligned implementation has made clear progress is wildfire management (Coogan et al. 2020; Williamson et al. 2019). Practices such as earlier fire season preparedness, strategic use of controlled burns, fuel load reduction, and improved infrastructure protection are increasingly common (Erni et al. 2024; Williamson et al. 2019). Governments continue to invest in fire response training, capacity-building, and inter-agency coordination to improve forest resilience (Government of Canada 2024c).

Table 4.1. Non-exhaustive summary of adaptation and mitigation actions implemented in Canadian forests, incorporated into government reports or journal articles, and analyzed in Antwi et al. (2024a; 2024b). [*Source*: Adapted from Antwi et al. (2024b)]

Management Category	Practice	Provinces Implemented	CSF Component (A: Adaptation; M: Mitigation; S: Social)	Reference
Forest Management & Silviculture	Management of forest age structure	BC, SK	A & M	(CCFM 2020; Devisscher et al. 2021; Government of Saskatchewan 2013)
	Stand thinning & pruning	BC, AB	A & M	(Devisscher et al. 2021; Harris et al. 2011; Wang et al. 2019)
	Clearing of underbrush	AB	A	(Christianson et al. 2013)
	Logging as a fuel management strategy	BC	A	(Devisscher et al. 2021)
	Ladder fuel removal	BC	A	(Devisscher et al. 2021)
	Adjusting of stocking standards/stand density	BC	M	(Devisscher et al. 2021)
	Prescribed/controlled burning & cultural burning	BC	A & S	(Devisscher et al. 2021)
	Creation of fuel breaks	BC	A & M	(Devisscher et al. 2021)

(Continued on next page. See notes at end of table.)

Table 4.1. Continued

Management Category	Practice	Provinces Implemented	CSF Component (A: Adaptation; M: Mitigation; S: Social)	Reference
Tree Planting & Afforestation	Fast-growing plantations	BC, AB, SK, MB, ON, QC	M	(Dominy et al. 2010)
	Tree planting initiatives	ON, MB	A & M	(CCFM 2020; Government of Ontario 2017; Ministry of Forests, Lands, Natural Resource Operations and Rural Development 2020)
	Short-rotation woody biomass afforestation trials	MB	M	(CCFM 2020)
	Reforestation of legacy natural disturbances	AB	A & M	(CCFM 2020)
AM & Species Selection	AM trials	BC, AB, SK, QC	A	(Bellringer 2017; Benomar et al. 2016; Forest Genetics Council of British Columbia 2021; Leech et al. 2011; Pedlar et al. 2011; Schreiber et al. 2013)
	Climate-based seed transfer	BC	A	(Forest Genetics Council of British Columbia 2021)
	Selection of drought-resistant phenotypes	AB, BC	A	(Devisscher et al. 2021; Niemczyk et al. 2019)

(Continued on next page. See notes at end of table.)

Table 4.1. Continued

Management Category	Practice	Provinces Implemented	CSF Component (A: Adaptation; M: Mitigation; S: Social)	Reference
AM & Species Selection	Provenance field trials for commercial tree species	AB	A	(Rweyongeza et al. 2015)
	Use of a mix of seeds for planting northern sites	QC	A	(Pedlar et al. 2011)
	Species diversification	BC	A	(Devisscher et al. 2021)
	Introduction of drought-tolerant species	BC	A	(Devisscher et al. 2021)
	Higher proportion of less flammable deciduous species	AB	A	(Devisscher et al. 2021)
Pest & Disease Management	Mountain pine beetle treatments	AB	A	(CCFM 2020)
	Spruce budworm treatments	NB, QC, NL	A	(CCFM 2020)

(Continued on next page. See notes at end of table.)

Table 4.1. Continued

Management Category	Practice	Provinces Implemented	CSF Component (A: Adaptation; M: Mitigation; S: Social)	Reference
Conservation & Protected Areas	Expansion of protected areas	SK, MB	M & S	(Government of Manitoba 2020; Government of Saskatchewan 2021)
	Addition to the provincial natural areas network	AB	M & S	(Government of Manitoba 2020)
	Caribou habitat recovery (expansion of protected areas increase carbon offset)	BC	M & S	(CCFM 2020)
Carbon Sequestration & Offset Initiatives	Management of moist forests for continuous cover	BC	A & M	(Devisscher et al. 2021)
	Carbon offset projects	BC	M	(van Kooten et al. 2015)

(Continued on next page. See notes at end of table.)

Table 4.1. Continued

Management Category	Practice	Provinces Implemented	CSF Component (A: Adaptation; M: Mitigation; S: Social)	Reference
Soil & Stand Rehabilitation	Rehabilitation planting of understocked stands	BC	M	(Devisscher et al. 2021)
	Fertilization of new plantings with high retention to maintain a seed bank	BC	A & M	(Devisscher et al. 2021)
	Salvage harvesting	BC	A & M	(BC Timber Sales 2021)

[Note: AB = Alberta; BC = British Columbia; MB = Manitoba; NB = New Brunswick; NL = Newfoundland and Labrador; ON = Ontario; QC = Québec; SK = Saskatchewan]

4.2 CSF Case Studies

Although research on CSF has recently gained momentum, the number of CSF-specific publications remains limited. In many cases, CSF practices are embedded within broader SFM efforts and are not identified as distinct initiatives. This overlap has led to inconsistencies in how climate-smart practices are defined, applied, and reported (Antwi et al. 2024a; Cooper et al. 2023). As a result, the climate adaptation and mitigation benefits of these practices are often under-reported or implicitly subsumed within SFM.

Nevertheless, the emergence of formal CSF guidelines, growing scientific attention, and the implementation of pilot projects are helping to clarify CSF as a distinct and essential forestry paradigm (Edwards et al. 2015; NCASI 2023; Williamson et al. 2019). Despite being under-represented in scientific publications, CSF has been evident in practical applications, such as community-led projects and the continuation of traditional practices like cultural burning (Table 4.2).

Table 4.2. Select examples of CSF initiatives, including project objectives, methods, outcomes, and references.

Category	Initiative/Case Study	Objective(s)	Outcome(s)	CSF Component (A: Adaptation; M: Mitigation; S: Social)	Reference
Prescribed Fire & Indigenous Peoples–Led Cultural Burning	BC Timber Sales–Glacier Creek Prescribed Fire, British Columbia (2021)	Reduce post-harvest fuel loads; decrease future wildfire risk; site prep for planting	Successfully removed accumulated dead wood and competing vegetation. Improved tree growth. Provided training opportunity for BC Wildfire Service crews.	A+M+S	(Cultural Burning and Prescribed Fire 2025)
Reforestation & Post-Fire Recovery	Flash Forest drone-based technology to regenerate the Assinica Wildlife Reserve, Québec, post-fire (2023)	Use drone technology to seed 100 ha of burnt forest with 2.5 million seeds (black spruce and jack pine)	Seedling survival was low in areas with high organic matter accumulation, but approach presents a quick and effective alternative to reforest after wildfire.	A+M	(Boisclair 2024)
SFM & Reconciliation	Wiliams Lake First Nation and West Fraser Joint Development Agreement, British Columbia (2024)	A collaborative agreement between Williams Lake First Nation and West Fraser established a First Nations Woodland License, allowing Indigenous Peoples–led management of local forest tenure; combining local tenure volumes	Supports economic self-determination. Coordinated approach to forest management, creating long-term employment opportunities and economic benefits for the community.	S	(Wood & Panel USA 2024)
Assisted Migration	Whitebark pine translocation out of its present geographical range (*Pinus albicaulis*), British Columbia (2007)	Assist the relocation of the endangered whitebark pine (*Pinus albicaulis*) to northern plots outside of the current geographic range and within predicted future ranges	Around 7% of seeds produced seedlings that survived, confirming that successful establishment is possible.	A	(Sáenz-Romero et al. 2020)

4.2.1 *Case Study: Full CSF Implementation with Mosaic Forest Management*

Mosaic Forest Management Corp. offers a leading example of full-spectrum CSF implementation in Canada. Operating on both public and private lands across Vancouver Island and coastal British Columbia, Mosaic integrates climate resilience, mitigation, and community engagement into every layer of its forestry operations. The company has formally aligned with SFI's CSF objectives (see Appendix A) and received SFI's Leadership in Conservation Award in recognition of its achievements (Sustainable Forestry Initiative 2023; Figure 4.1).

Mosaic's operations represent more than the application of isolated climate-smart practices; they showcase a systematic, organization-wide integration of CSF principles across strategic planning, operational execution, and social responsibility. Below is a breakdown of CSF components as applied by Mosaic.

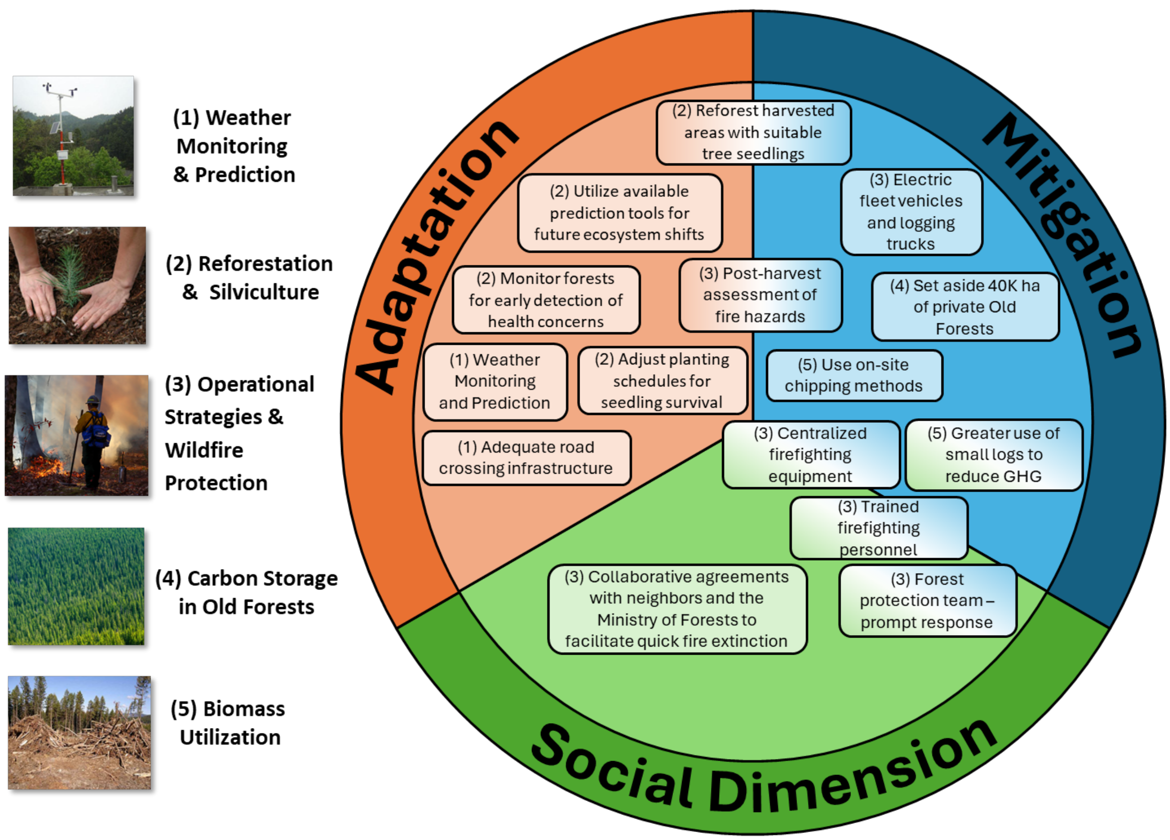


Figure 4.1. Mosaic's CSF strategies as implemented in their forest management.
[*Source*: Mosaic (2023b)]

Adaptation:

- *Climate-Informed Planning:* Mosaic integrates localized weather monitoring, remote sensor networks, and predictive modelling to inform both short- and long-term decision-making. This enables real-time adaptation, such as scheduling harvests based on snowpack conditions or anticipating drought stress (Mosaic 2023b).

- *Resilient Reforestation and Silviculture:* Mosaic follows BC's Climate-Based Seed Transfer system, aligning seed sources with future climatic projections (O'Neill et al. 2017). Their Saanich seed orchard has supported over 300 million seedlings since 1979 (Mosaic 2023b), ensuring high-quality, climate-resilient genetic stock. Mosaic has also reintroduced species like blister rust-resistant western white pine (*Pinus monticola*) to promote forest resilience (TimberWest 2025).

- *Operational Strategies for Wildfire Risk Reduction:* To mitigate fire risk, Mosaic implements proactive strategies, including small log salvage, chipping, and firewood redistribution. They also maintain a dedicated forest protection team and collaborate with the BC Ministry of Forests and neighbouring landowners for coordinated fire response (Mosaic 2024).

Mitigation:

- *Carbon Storage in Old Forests:* Through the BigCoast Forest Initiative, Mosaic has deferred 40,000 ha of old-growth forest for at least 25 years. This area is projected to sequester over 20 million tonnes of CO_2e while maintaining habitat for old-seral obligates, cultural sites, and watersheds (Mosaic 2023b; Sustainable Forestry Initiative 2023). It is the largest private forest carbon project in Canada (Mosaic 2023b).

- *Emission Reductions and Carbon Accounting:* Mosaic has tracked its corporate carbon footprint since 2016 and targets net-zero emissions by 2035 (Mosaic 2023b). Initiatives include transitioning the fleet vehicles to electric, centralizing dispatch operations to reduce fuel consumption, diverting slash to bioenergy and pulp instead of open burning, enhancing soils with biosolids, and using genetically improved seedlings to increase carbon uptake (Mosaic 2023b).

- *Carbon Credit Generation:* Carbon credits from the BigCoast initiative are sold on voluntary markets. Revenues support conservation and cultural projects, including partnerships with the Pacific Salmon Foundation and the Indigenous Protected and Conserved Innovation Program (Mosaic 2023b).

Social Dimension:

- *First Nations and Community Engagement:* Mosaic maintains formal agreements with 15 coastal First Nations and collaborates on shared land-use objectives. It is the first forestry company in BC to earn the Progressive Aboriginal Relations certification, recognizing its leadership in Indigenous engagement (Mosaic 2023a).

- *Community Economic and Educational Support:* The company supports long-term employment through sustainable harvesting and by redistributing wood via a firewood program, with proceeds supporting local organizations (Mosaic 2024). Mosaic also conducts outreach and education initiatives to raise public awareness and build support for CSF practices (Mosaic 2023a).

5.0 ECOSYSTEM SERVICES

5.1 Ecosystem Service Definition and Types

ES refer to the broad array of benefits that humans derive, directly or indirectly, from ecosystems. These services span from freshwater and timber to cultural identity, climate regulation, and recreation. The concept has undergone significant evolution since its emergence in the 1990s. Foundational works by Daily (1997) and Constanza et al. (1997) brought widespread attention and recognition of the critical role ecosystems play in supporting human well-being. Building on these insights, the Millennium Ecosystem Assessment (2005) formalized a widely adopted typology of ES, organizing them into four core categories: provisioning, regulating, supporting, and cultural (Table 5.1). These categories have been foundational in shaping environmental policy and valuation methods throughout the early 2000s and remain a reference point in both policy and science (Holzwarth et al. 2020). However, growing demand for standardized, policy-relevant metrics led to the emergence of updated classification systems (Appendix F).

One of the most influential revisions to the concept is the Common International Classification of Ecosystem Services (CICES), developed by the European Environmental Agency. Since its inception in 2013 and further refined in versions 5.1 and 5.2 (as of October 2023), CICES simplifies ES into three categories: (1) *provisioning services*, contributions to material and energy needs; (2) *regulation and maintenance services*, contributions to a livable environment; and (3) *cultural services*, non-material effects on people's physical and mental well-being.

Importantly, supporting services are no longer a separate category in CICES; rather, they are recognized as the underlying biophysical processes that enable the production of all other ES (CICES 2024). Canada has aligned its national ecosystem service reporting with the CICES three-category model, as reflected in Statistics Canada's environmental accounts (Statistics Canada 2022).

Despite minor differences among classification systems, they all converge on a fundamental conclusion: biodiversity, ecosystem function, and ecological resilience are integral for the sustained delivery of ecosystem services (Brockerhoff et al. 2017; Holzwarth et al. 2020; Thom et al. 2016).

Table 5.1. ES Type, as proposed by the Millennium Ecosystem Assessment (2005), along with descriptions, and examples provided by forests.
[*Source*: Adapted from Alcamo et al. (2003); Holzwarth et al. (2020)]

Ecosystem Service Type	Description	Examples
Provisioning	Material products obtained directly from ecosystems	• Food (e.g., berries, mushrooms) • Fresh water • Fuelwood • Fiber • Timber • Biochemicals (e.g., medicines) • Genetic resources • Habitat
Regulating	Benefits from natural regulation of ecosystem processes	• Climate regulation (carbon storage, microclimate buffering provided by tree canopies) • Air quality • Disease regulation • Water regulation • Water purification • Pollination • Erosion and landslide control • Flood control
Cultural	Non-material contributions to human well-being	• Spiritual and religious values • Recreation and ecotourism • Aesthetic inspiration • Educational and scientific research • Sense of place • Cultural heritage
Supporting	Fundamental ecological processes enabling all other services	• Soil formation • Nutrient cycling • Primary production • Pollination and seed dispersal • Ecosystem resilience and adaptation • Decomposition and organic material recycling

5.2 Forest Ecosystem Services: Interactions, Trade-offs, and Dynamics

Forests are among the most multifunctional ecosystems on earth, providing a wide array of ES across spatial and temporal scales (Table 5.1). In Canada, managed forests, which account for approximately 62% of the country's total forested area (230 Mha out of 369 Mha [NRCan 2025d]), play a central role in global climate regulation. For example, Canada's boreal forests store between 28 and 30 billion metric tons of carbon in biomass, dead organic matter, and soils (Kurz et al. 2013), making them globally significant carbon reservoirs. These forests also provide additional ecosystem services beyond carbon storage, contributing to water regulation, biodiversity conservation, cultural values, and economic livelihoods.

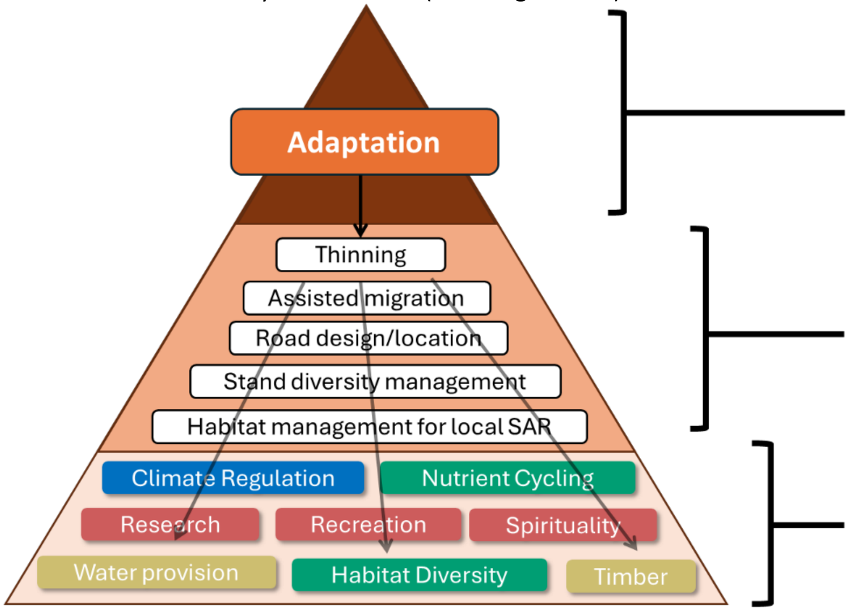
Canada's forests support vast networks of wetlands, lakes, and rivers, which are essential to maintaining regional and national hydrological cycles. For many Indigenous communities, forests are deeply connected to cultural identity, spiritual practices, traditional food systems, and intergenerational knowledge (Armstrong et al. 2021; 2023).

However, the provision of ES is dynamic, fluctuating across time and space, and is influenced by both natural and anthropogenic disturbances, as well as successional processes (Dhar et al. 2016; Nyland 2011; Qiu et al. 2018; Rodríguez et al. 2006). This complexity gives rise to what is known as the *disturbance paradox*, where a single disturbance event can simultaneously diminish and enhance different ES (Thom et al. 2016). For example, the mountain pine beetle outbreak that impacted western Canadian forests in the early 2000s significantly reduced timber supply and compromised water and carbon regulation. At the same time, it also created new habitat for some species of woodpeckers (Dhar et al. 2016; Edworthy et al. 2011). Similarly, wildfire mitigation strategies such as thinning or prescribed burning may result in short-term carbon losses but enhance long-term forest resilience and reduce the likelihood of catastrophic wildfire (Beverly et al. 2021; LM Forest Resource Solutions Ltd. 2020).

These examples illustrate the inherent trade-offs and synergies among ES. Forest management must navigate a complex balancing act: weighing short- vs. long-term outcomes; site-level dynamics vs. landscape-level planning; and ecological resilience vs. economic viability. To do so effectively, forest practitioners require a robust understanding of ecosystem processes, feedback mechanisms, and inter-service relationships (see Box 1). This knowledge is critical for designing interventions and sustaining the delivery of ecosystem services over time, while adapting to an uncertain future climate.

Box 1: Linking CSF to Ecosystem Services

CSF integrates three interrelated components—adaptation, mitigation, and the social dimension—with the goal of sustaining and enhancing ES. These relationships can be conceptualized as a three-tiered pyramid: (1) CSF component, (2) forest management strategy, and (3) ecosystem service outcomes. This structure clarifies how high-level climate-smart goals translate into forest management actions, which in turn influence the quantity, quality, and distribution of ecosystem services (see image below).



CSF Component (Top): At this level, an organization defines its climate-smart objectives within one of the CSF components (Adaptation, Mitigation, Social)

Forest Management Strategy (Middle): To achieve CSF goals, specific silvicultural or operational practices are selected based on local forest conditions, predictive climate models, and stakeholder priorities that advance CSF component goals.

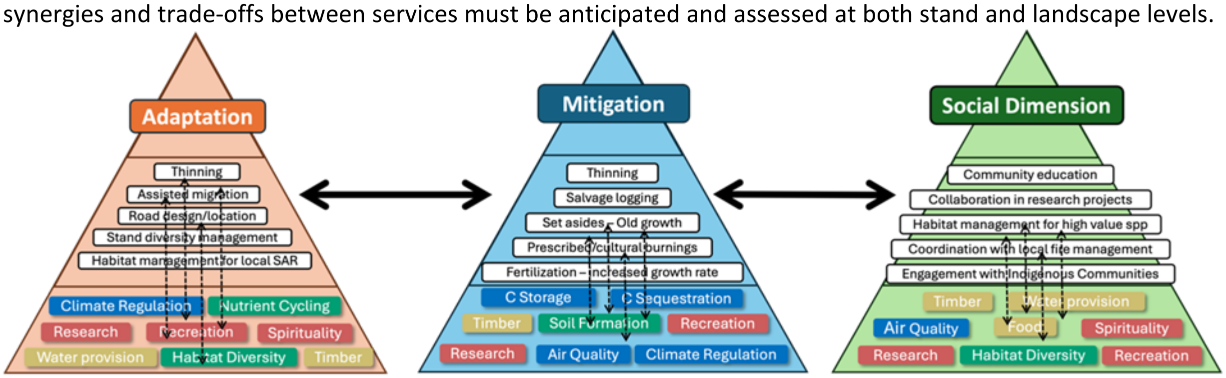
Ecosystem Service Outcomes: Implementing a forest management strategy produces a suite of ES effects—some positive, some negative—that must be considered and evaluated holistically.

Example: Enhancing Forest Resilience to Drought

CSF Component: Adaptation
Forest Management Strategy: Pre-commercial thinning to reduce stand density and lower competition for resources (e.g., water).
Ecosystem Service Interaction (Expected Direction of Change): ↔neutral, ↑ increase, ↓ decrease):

- **Water availability** ↑ Moderate–High
- **Carbon storage** ↓ Short term; ↑ Long term
- **Wildlife habitat** ↔Variable, Species dependent
- **Merchantable Timber & Biomass:** ↔or ↑ Short term; ↑ Long term

Explanation: This example demonstrates how a single adaptation practice (thinning) can simultaneously enhance regulating services (e.g., water retention), involve short-term trade-offs in carbon storage, and have variable effects on supporting and provisioning services (e.g., habitat and timber). Additionally, because CSF actions across multiple components are often implemented concurrently, and because forest ecosystems differ widely across landscapes, synergies and trade-offs between services must be anticipated and assessed at both stand and landscape levels.



6.0 ECOSYSTEM SERVICES TRADE-OFFS

6.1 Framing Trade-offs in Forest Management

In land and forest management, ES trade-offs arise when enhancing one or more service inadvertently reduces the provision of others, either immediately or over time (Turkelboom et al. 2018). These trade-offs are often intrinsic to decisions that prioritize specific outcomes, such as maximizing wood or pulp production, carbon storage, water regulation, or biodiversity conservation. For example, intensive harvesting to optimize timber yields may diminish long-term carbon sequestration, compromise habitat quality, and disrupt hydrological functions, particularly if not properly balanced with spatial and temporal planning considerations (Pohjanmies et al. 2017). Conversely, synergies occur when a single management action benefits multiple ES. For instance, mixed-species regeneration can enhance both carbon storage and biodiversity (Littlefield et al. 2022; Muys et al. 2023).

Achieving the integrated objectives of CSF requires deliberate efforts to recognize, assess, and reconcile these trade-offs and synergies. Doing so ensures development of strategies that maximize overall forest benefits while preserving ecological integrity and promoting human well-being.

6.2 Literature Review: Exploring ES Trade-Offs in Forest Management

To assess how ES trade-offs and synergies have been treated in the scientific literature, a structured literature review was conducted using Google Scholar. Search terms included “ecosystem services,” “trade-off,” “synergy,” “Canada,” “forest,” “boreal,” and “forest management.” The results were filtered for English-language, peer-reviewed articles published between 1997 and 2024. The initial search returned over 1,300 articles. The first 200 were screened by relevance, stopping when 10 consecutive papers proved unrelated. Articles were considered relevant if they mentioned “trade-off(s),” “synergy/synergies,” and “ecosystem service(s)” in the title, abstract, keywords, or body text.

This process retained 20 studies, and an additional 25 were sourced through citation mining, producing a final dataset of 45 articles (Appendix G). These were then classified into five themes: (1) ES assessment methods, (2) ES across scales, (3) forest management and resilience, (4) stakeholders and governance in ES, and (5) trade-offs and synergies. From these, 24 forestry-oriented studies that directly addressed ES interactions were further analyzed (Table 6.1).

Most of the reviewed articles examined trade-offs between timber production and other ES, with 54% (n = 13 out of 24) focusing on biodiversity, 37.5% (n = 9) on carbon storage, 20% (n = 5) on habitat quality, and 17% (n = 4) on water regulation. The most commonly reported synergy was timber production with carbon sequestration (17%), followed by timber production and emissions reductions (12.5%, n = 3). These results are further detailed in sections 6.2.2 through 6.2.5.

Table 6.1. Matrix of trade-offs and synergies occurring between es delivered by the forest under forest management (review of 24 published papers between 1997 and 2024).
[*Source*: (1) Duncker et al. (2012); (2) Gutsch et al. (2018); (3) Mazziotta et al. (2022); (4) Morán-Ordóñez et al. (2020); (5) Schwaiger et al. (2019); (6) Blattert et al. (2023); (7) Blattert et al. (2020); (8) Daigneault et al. (2024); (9) Diaconu et al. (2017); (10) Felton et al. (2024); (11) Gregor et al. (2022); (12) Gregor et al. (2024); (13) Habib et al. (2016); (14) Hanna et al. (2020); (15) Hoek van Dijke et al. (2022); (16) Iglesias et al. (2022); (17) Littlefield et al. (2022); (18) Pohjanmies et al. (2017); (19) Schwenk et al. (2012); (20) Soimakallio et al. (2021); (21) Steenberg et al. (2011); (22) Strengbom et al. (2018); (23) Vergarechea et al. (2022); (24) Ziter et al. (2013)]

		Trade-Offs										
Synergies	**ES Interaction**	**Timber Production**	**Carbon Sequestration**	**Carbon Storage**	**Biodiversity**	**Habitat Quality**	**Water Regulation**[a]	**Non-Timber Products**[b]	**Soil Quality**	**Climate Regulation**	**Cultural Services**	**Emissions Savings/ Sustainable C**[c]
	Timber Production		(3)(5)	(2)(7)(13)(14)(17)(18)(19)(20)(21)	(1)(3)(5)(6)(7)(10)(11)(12)(13)(16)(19)(22)(23)	(2)(8)(14)(17)(21)	(4)(5)(13)(14)	(22)	(1)(3)	(11)	(23)	
	Carbon Sequestration	(4)(5)(8)(10)										
	Carbon Storage	(22)			(16)		(2)					(20)
	Biodiversity			(7)(20)			(5)					(5)(6)(12)(20)
	Habitat Quality			(2)	(2)(16)		(2)					
	Water Regulation[a]	(2)(9)			(4)(5)					(15)		(5)
	Non-Timber Products[b]					(3)			(4)			
	Soil Quality		(4)									
	Climate Regulation			(20)								
	Cultural Services											(6)
	Emissions Savings/ Sustainable C	(3)(5)(13)			(5)					(6)		

Note: The limited existing literature on this subject in Canada prevented the generation of a matrix constrained to the Canadian context, alone.
[a] Including groundwater recharge.
[b] Including mushrooms, berries, etc.
[c] Including bioenergy, C storage in long-lived wood products, substitution-based C benefits.

6.2.1 *Methods and Approaches to Assess ES Trade-Offs*

Despite growing interest in CSF, significant uncertainties remain regarding the magnitude and direction of ES trade-offs under different forest management regimes. To date, there has been no comprehensive review on how CSF components explicitly interact with ES trade-offs, although broader research on ES interactions across land-use types offers partial insights (Habib et al. 2016; Sullivan et al. 2024; White et al. 2024). Selected publications from this wider body of literature are included in Appendix G.

Effective assessment of ES interactions depends heavily on tools and methodologies available to decision-makers. Neugarten et al. (2018) categorized ES assessment tools into two major groups (Table 6.2):

1. *Written Guidance Tools:* These resources typically include measurement protocols, checklists, and explanatory documents. For example, Canada's Ecosystem Services Assessment Toolkit, developed collaboratively by federal, provincial, and territorial authorities, combines case studies, practical worksheets, and technical fact sheets (Value of Nature to Canadians Study Taskforce 2017).

2. *Computer-Based Modelling Tools:* These tools enable spatial and scenario-based ES assessments. Examples include Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) and Artificial Intelligence for Ecosystem Services (ARIES), both of which are freely available and adaptable across geographies (Neugarten et al. 2018).

Table 6.2. List of common ecosystem services assessment tools included in the IUCN review of tools for measuring, modelling, and valuing ecosystem services. [*Source*: Adapted from Neugarten et al. (2018)]

Name and Website	Description	Citation
Written step-by-step tools		
Ecosystem Services Tool (EST) https://publications.gc.ca/	A free, hyperlinked PDF offering structured worksheets, recommended indicators, and a toolbox of methods, no modelling required.	(Value of Nature to Canadians Study Taskforce 2017)
Protected Areas Benefits Assessment Tool + (PA-BAT+) https://portals.iucn.org/	A free, adaptable, workshop-based tool assessing stakeholder perceptions of ecosystem service benefits, requiring no technical skills.	(Ivanic et al. 2020)
Toolkit for Ecosystem Service Site-Based Assessment v.2.0 (TESSA) https://www.birdlife.org/tessa-tools/	A free PDF guide offering low-cost, non-modelling methods to assess site-level nature benefits with stakeholder participation.	(Peh et al. 2013)
Computer-based modelling tools		
Artificial Intelligence for Ecosystem Services (ARIES) https://aries.integratedmodelling.org/	Modelling platform using k.LAB software for integrated ES analysis, supporting scenarios, valuation, and planning; it requires GIS and modelling skills.	(Villa et al. 2014)
Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) https://naturalcapitalproject.stanford.edu	GIS-based tool suited for mapping and quantifying ecosystem services under scenarios, using simple models and standard input data.	(Natural Capital Project 2025)
Social Values for Ecosystem Services (SolVES) https://www.usgs.gov/centers/geosciences-and-environmental-change-science-center/science/social-values-ecosystem	A GIS-based tool for mapping perceived cultural ES values using survey data, producing social value metrics and raster maps.	(Sherrouse et al. 2022)
WaterWorld (WW) https://www.policysupport.org/waterworld	Sophisticated, process-based modelling of baseline and scenario water quantity, water quality, soil erosion, and sediment transport.	(Mulligan 2013)

Despite the accessibility of these tools, implementation challenges persist. A review by Kerr et al. (2021) identified barriers such as limited conceptual understanding, institutional inertia, lack of regulatory incentives, or loss of expertise. Mechanistic approaches that trace the causal pathways between observed ES relationships remain rare. Dade et al. (2019) noted that only 19% (30 out of 158) of reviewed studies explicitly identified the drivers of ES trade-offs. To address this, Dade et al. (2019) proposed four key mechanistic pathways to guide evaluations of ES interactions (Table 6.3).

Table 6.3. Summary of possible mechanistic pathways of ES trade-offs and synergies. [*Source*: Adapted from Dade et al. (2019)]

Pathway	Driver Affects	ES Interaction	Likely Outcome	Example Driver	Example Outcome
Driver affects only one ES	One ES	No	No trade-off/synergy	A reforestation policy targeting abandoned agricultural land increases C sequestration but does not impact food production, because the land was not active	No trade-off or synergy between ES
Driver affects one ES, which interacts with another ES	One ES	Yes	Trade-off or synergy via interaction	Reforesting active cropland boosts C sequestration but reduces food production because of competition for land	Trade-off: gains in one ES (carbon) result in losses in another (food provisioning)
Driver affects two ES independently, but they do not interact	Two ES	No	Parallel synergy or trade-off	Riparian vegetation restoration increases both crop production (via improved soil retention) and C sequestration (through added biomass), but ES operate independently	Positive synergy despite no interaction between ES
Driver affects two ES, and they also interact	Two ES	Yes	Complex outcome; often negative synergy	Urban expansion reduces both forests and croplands (direct effects), and these land uses also compete (interaction); as a result, both food production and carbon storage decline	Negative synergy: both ES decline together

To simplify complex assessments, Cord et al. (2017) suggested grouping ES into “bundles” that tend to co-occur across landscapes. They also advocate for optimization algorithms like Multi-Objective Land Use Allocation to generate Pareto-efficient solutions[11], where these solutions balance multiple services without requiring extreme trade-offs. In a practical application, Gregor et al. (2024) used this approach to show that strict land protection policies in Europe (e.g., setting aside 10% of land) can reduce management flexibility and inadvertently divert pressure to other regions.

Similarly, InVEST has proven useful in real-world planning. In Hawaii, Goldstein et al. (2012) demonstrated how the tool can model trade-offs among carbon sequestration, water supply, and economic returns. Their analysis helped identify the multifunctional landscapes that support diverse community needs across agriculture, urban development, and forestry. Limitations are identified, particularly regarding data sensitivity and scale. As noted by Benez-Secanho et al. (2019), the accuracy of these tools often hinges on resolution and the extent of available datasets.

Ultimately, selecting an appropriate ES assessment tool should consider three factors (Neugarten et al. 2018): (1) primary purpose of the analysis (e.g., informing site management or comparing policy scenarios); (2) desired outputs (qualitative vs. quantitative, monetary vs. non-monetary); and (3) practical constraints, including available data, time, budget, and spatial resolution.

6.2.2 ES Trade-Offs from Governance and Stakeholder Perspectives

Effectively managing ES trade-offs requires navigating complex governance challenges, including unequal stakeholder influence, conflicting land-use values, and ecological dynamics that operate across multiple spatial and temporal scales (Glick et al. 2021; Kalafatis et al. 2019; Pohjanmies et al. 2017; Qiu et al. 2018; Rodríguez et al. 2006; Schulte 2024; Tol 2005; Turkelboom et al. 2018). These trade-offs may arise from deliberate policy decisions or unintentionally due to changes in landscape management (Pohjanmies et al. 2017; Rodríguez et al. 2006).

There can be asymmetry among various stake-, rights-, and landholders that leads to a necessity of inclusive governance frameworks that explicitly address disparities in power and influence (Turkelboom et al. 2018). Howe et al. (2014) proposed three indicators that signal a high likelihood of trade-offs emerging:

1. The presence of stakeholders with private or competing interests in natural resources;
2. Evidence of conflict between provisioning and non-provisioning ES;
3. A decision-making context primarily shaped by local-scale actors.

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[11] In multi-objective optimization (such as, when managing for multiple ES), the Pareto frontier (also known as Pareto Front, or Pareto Curve) is a set of non-dominant, optimized, and efficient solutions. It is defined as a trade-off between non-dominant solutions in which it is impossible to make any individual cost function better without making at least one individual cost function worse off. The Pareto frontier is based on the preferences of the designer, and the best solution depends on the importance assigned to each objective. This method can support decision-making processes.

While these indicators can serve as useful early warning signs, they do not imply that trade-offs are inevitable. Rather, the proactive identification and integration of potential trade-offs into planning processes may offer more effective pathways for promoting synergies focused on maximizing mutual benefits (Howe et al. 2014).

The way ES assessments are framed influences which impacts become visible and prioritized (Schulte 2024). Supply-side assessments typically focus on biophysical outputs, while demand-side approaches emphasize the values, needs, and preferences of different stakeholder groups (Schulte 2024). A balanced approach that integrates both perspectives is more likely to reveal latent or hidden conflict and improve governance outcomes. Given that ES interactions can shift across time and space, governance systems must be adaptive, multi-level, and responsive to ecological and social feedback loops (Qiu et al. 2018).

Forward-looking governance models are most effective when they anticipate change, engage a broad range of stake-, land-, and rights-holders, and co-produce management objectives that incorporate carbon, biodiversity, and cultural values (Glick et al. 2021). This is particularly important in the Canadian context, where the Crown has the duty to consult Indigenous Peoples as a requirement enshrined in section 35 of the Constitutional Act, 1982 (Library of Parliament 2019).

At the broader policy level, trade-offs can also manifest between adaptation and mitigation objectives within climate policy (Tol 2005). Although both are necessary, they typically function on different scales: adaptation efforts are often local and short term, whereas mitigation strategies are regional, national, or international in scope and designed for longer time horizons (Tol 2005). This mismatch complicates cost-benefit analyses and underscores the importance of integrated planning approaches. However, opportunities exist to align these goals. For example, facilitative adaptation actions, such as investing in infrastructure or healthcare, can simultaneously strengthen societal resilience and support mitigation outcomes, particularly when coordinated through national policy (Tol 2005).

6.2.3 *ES Trade-Offs Across Time and Space*

Forests present a unique challenge for managing ES trade-offs due to their structural complexity, dynamic ecological processes, and long life cycles of trees (Mori et al., 2017; Steel et al. 2024). Many of these processes unfold over decades or even centuries, making it essential to understand when and where trade-offs occur as well as their potential reversibility (Rodríguez et al. 2006).

Spatial and temporal scales play a crucial role in shaping trade-off intensity and visibility. Broader spatial planning often enables more balanced outcomes among competing ES. For example, Ziter et al. (2013) found that in managed Québec forests, carbon storage and biodiversity goals were more compatible when interventions prioritized landscape-level connectivity. In fact, carbon storage in these managed systems sometimes exceeded that of unmanaged forests, underscoring the potential of strategic management at the landscape scale. Similarly, White et al. (2024) found that intensively managed Acadian forest stands in eastern Canada could support tree species diversity, provided that management actions were spatially distributed and heterogeneity was maintained across the landscape. This reinforces the importance of scale-sensitive planning in reconciling conservation and production objectives (White et al. 2024). Findings from Finland further underscore this principle. Pohjanmies et al. (2017) demonstrated that managing trade-offs between timber production and carbon storage was more effective when planning extended over larger areas (>200 ha), whereas stand-level approaches typically intensified service conflicts.

Overall, effective forest management requires coordination beyond individual plots or stands. Regional, watershed, or landscape-scale planning that incorporates variation in forest age, canopy structure, and species composition can build resilience and maintain the delivery of multiple ES under shifting climate and disturbance regimes (Steel et al. 2024).

6.2.4 *ES Trade-Offs and Synergies*

The body of literature addressing ES trade-offs and synergies within forest management remains limited. While some studies examine the broad management scenarios, such as comparing business-as-usual with nature protection models, fewer investigate how particular silviculture treatments affect the balance among ES (Gutsch et al. 2018; Mazziotta et al. 2022; Morán-Ordóñez et al. 2020; Schwaiger et al. 2019).

At broader spatial scales, synergies among regulating services are more frequently observed, particularly when management goals are diversified across heterogeneous landscapes (Gutsch et al. 2018; Morán-Ordóñez et al. 2020; Strengbom et al. 2018). In contrast, trade-offs tend to be more localized and often stem from prioritizing provisioning services at the expense of others (Cord et al. 2017). For example, Strengbom et al. (2018) found that thinning treatments in the boreal forest improved yields of lichen and berries but resulted in reduced carbon storage at the stand scale. However, such localized trade-offs were mitigated when viewed from a broader landscape perspective. Likewise, Sullivan et al. (2024) found that low-density thinning (<1,000 stems/ha) in second-growth lodgepole pine (*Pinus contorta*) stands promoted partial convergence toward old-growth structural characteristics and supported mammalian species richness comparable to older forests. This suggests that some structural trade-offs may be minimized through targeted interventions that simultaneously maintain biodiversity values.

6.3 Balancing Ecosystem Services Trade-Offs

Effectively balancing trade-offs among ES requires adaptive forest management approaches that incorporate monitoring, modelling, and stakeholder engagement. CSF strategies must be evaluated not only in terms of their ecological effectiveness but also for their performance across spatial and temporal dimensions and across the full spectrum of service types.

This process begins with the systematic assessment of trade-offs (as discussed in section 6.2.1). Analytical tools such as ES models (Grêt-Regamey et al. 2017; NatCap Stanford 2025), Multi-Criteria Decision Analysis, and indicator-based evaluations (NCASI 2021b) can help managers quantify and balance trade-offs under a range of management and climate scenarios (Gregor et al. 2022).

At the stand level, decisions should account for interactions between carbon storage and biodiversity. For instance, landscape-scale climate adaptation strategies can support structural diversity while maximizing carbon sequestration (Littlefield et al. 2022). This dual focus becomes especially important when aligning with the values and goals of diverse stakeholders, landowners, and rights-holders, including Indigenous communities, local residents, the forest industry, and policymakers. Participatory planning processes that integrate multiple perspectives early in the decision-making process help enhance legitimacy and long-term sustainability.

6.3.1 *Leveraging Decision Support Systems*

A promising pathway to achieving multiple CSF objectives is the adoption of Decision Support Systems (DSS[12]), particularly those incorporating Multi-Criteria Decision-Making methodologies. These systems, often referred to as multi-criteria decision support systems, have supported forest managers since the late 1990s and continue to evolve in their capacity to support complex forest planning (Belton et al. 2002; Blattert et al. 2020; Diaz-Balteiro et al. 2008; Kangas et al. 2005; Kpadé et al. 2024; Schwenk et al. 2012; Thrippleton et al. 2021).

Modern multi-criteria decision support systems platforms incorporate climate projections, biodiversity indicators, social values, economic goals, and ecosystem service models within a unified framework (ForestDSS 2024). They are increasingly used to

- Evaluate trade-offs and synergies under alternative climate scenarios (Biber et al. 2020; Mutterer, Blattert, et al. 2025; Thrippleton et al. 2021);
- Align silviculture practices with international climate goals (Luyssaert et al. 2018);
- Incorporate ecosystem disturbances, such as wildfire, into long-term scenario planning (Mutterer, Schweier, et al. 2025).

In Canada, DSS applications have been customized using tools such as CBM-CFS3 and the FORECAST modelling suite. One example is the composite system developed by Seely et al. (2004) for a 288,000-ha forest in British Columbia. This system integrates stand-level growth models (FORECAST), harvesting scheduling (Aggregate Timberland Assessment System—ATLAS), habitat modelling (SIMFOR), and landscape visualization (CALP). Such integrated platforms allow users to explore the implications of different scenarios and support evidence-based decisions that align with CSF principles.

6.3.2 *Shifting Tree Species Composition of Future Forests*

Both natural dynamics and human interventions influence forest species composition. While large-scale disturbances, such as wildfire or insect outbreaks, can rapidly shift forest structure, natural migration of tree species is typically slow due to limited dispersal capabilities, long generation times, and local priority effects (Solarik et al. 2020; Vissault et al. 2020).

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[12] Although a DSS can in principle be any system that aids decision-makers, the term typically refers to model-based software systems that provide a user interface, a “knowledge system” (database, models, etc.), and a “problem processing system” (Segura et al. 2014).

Climate change adds further complexity by pushing populations beyond their adaptive limits, especially at range limits (Solarik et al. 2018). AM and the introduction of climate-resilient species offer promising tools for adapting forest composition, though these approaches must account for site-specific conditions, including soil, climate, and ecological compatibility. For example, planting broad-leaved species beyond their current range can diversify conifer-dominated forests, potentially increasing resilience and productivity under future climate (Government of Canada 2023; Urgoiti et al. 2022; 2023).

6.3.3 *Proactively Managing and Preparing for Disturbances*

As the frequency and intensity of forest disturbances increase with climate change (Ameray et al. 2023), proactive management becomes critical to minimize trade-offs and maintain ES delivery. Interventions such as prescribed burns and thinning have been shown to reduce wildfire severity while preserving carbon stocks and timber values (Beverly et al. 2020).

Increasing the proportion of broad-leaved trees and expanding set-aside areas can also buffer forests from disturbance-related impacts (Ameray et al. 2023). However, rapid changes in forest composition may delay natural recolonization by desirable species, posing risks to long-term ecosystem functioning (Reich et al. 2022). To address these risks, forest managers must incorporate disturbance mitigation into long-term plans. Practices such as fuel reduction and strategic thinning can enhance structural resilience and reduce fire severity (Karimi et al. 2024). Integrating these practices into climate adaptation frameworks supports sustained ES delivery in an increasingly variable environment.

6.3.4 *Considering Forestry Set-Asides*

Designating portions of managed forests as set-aside or unmanaged reserves plays a critical role in maintaining biodiversity and non-timber ES. While such areas may reduce harvestable volume, they contribute to long-term ecological resilience and help meet conservation targets. Recent data indicate that approximately 52% of Canada's managed forest area is subject to conservation constraints, including riparian buffers, wetland exclusions, and deferred harvest zones (FPAC 2020). Prioritizing set-asides in ecologically significant or highly connected regions can increase their effectiveness (NCASI 2021c).

6.3.5 *Managing ES at the Landscape Level*

Landscape-level planning provides a powerful framework for reconciling trade-offs among ES by spatially distributing different management objectives across the forest mosaic (Table 6.4). Instead of expecting individual stands to fulfill all objectives, this approach supports functional zoning, whereby different parts of the landscape are managed for timber production, conservation, or ecological forestry (Himes et al. 2022; Messier et al. 2009).

This approach is exemplified by the TRIAD approach, which designates forest areas into three categories: (1) intensively timber production zone, (2) conservation reserves, and (3) ecosystem management zones that integrate ecological forestry principles. The proportions of each zone are flexible and should respond to local priorities, ecological constraints, and regulatory frameworks (Himes et al. 2022).

In 2004, Québec implemented a TRIAD framework in the Mauricie region (860,000 ha). The reallocation increased conservation areas from 2% to 11%, expanded intensive production to 20%, and designated 69% of the area for ecosystem-based management (Messier et al. 2009). In 2019, Nova Scotia adopted the TRIAD zoning to its entire public forest-land base (Himes et al. 2022). Protected areas already represented 33% of the land, and the province identified 16% for intensive management and allocated the remaining 51% to the ecological matrix (Himes et al. 2022). The province also developed a guide that outlines options for matrix ecological management in the region (Mcgrath et al. 2021).

Table 6.4. Potential to reduce trade-offs by managing at the landscape level vs. stand level.

Identified Trade-Off	CSF Component	Potential Trade-Off & Management	
		Stand Level	Landscape Level
Minimizing Ecosystem Vulnerability vs. Carbon Storage	Adaptation & Mitigation	**Trade-Off:** Fast-growing planted stands rapidly sequester carbon but are more vulnerable to drought and insect outbreaks, risking sudden carbon loss. **Management:** Use mixed-species plantings and multi-aged cohorts; apply adaptive thinning; monitor for early pest/disease signs.	**Trade-Off:** Homogeneous stand structures increase synchrony in disturbance risks, amplifying carbon loss. **Management:** Diversify stand composition across the landscape by mixing age classes, species, and structures. Create a mosaic of high-carbon older stands with harvested and regenerated (naturally and/or planted) stands.
Diversified Reforestation vs. Timber Harvesting	Adaptation & Social (Moderate Mitigation)	**Trade-Off:** Mixed-species stands enhance resilience and multifunctionality but may delay early timber yields and increase operational complexity. **Management:** Select marketable species; diversify wood products; apply variable retention and selective harvesting.	**Trade-Off:** A landscape dominated by timber production reduces resilience and under-represents non-market services (e.g., pollination). **Management:** Apply a landscape mosaic strategy (e.g., TRIAD approach; (Messier et al. 2009) ecosystem management, wood production, and conservation).
Carbon Sequestration vs. Biodiversity Conservation	Mitigation & Adaptation (Social co-benefit)	**Trade-off:** Even-aged monocultures optimize carbon storage but provide low habitat diversity and reduced biodiversity. **Management:** Retain legacy and seed trees; incorporate native broadleaf species; use variable retention harvesting to support structural heterogeneity and wildlife habitat.	**Trade-off:** Large tracts of regenerated stands may favour carbon sequestration but displace habitat for late-successional species. Conversely, dedicating more area to natural regeneration reduces overall short-term carbon accumulation. **Management:** Target artificial regeneration to sites unsuitable for natural regeneration; prioritize natural regeneration in high-biodiversity areas; connect mature forest patches with riparian corridors.

7.0 POTENTIAL ECOSYSTEM SERVICE TRADE-OFFS UNDER THE CSF FRAMEWORK

To gain insight into how CSF is being applied across Canadian forestry operations, we conducted a questionnaire in April 2024 among NCASI Member Companies. The goal was to assess the current state of CSF implementation, identify priority ecosystem services, and better understand where potential conflicts may emerge (Figure 7.1). Of the 16 respondents, the top three ES identified as management priorities were biodiversity and habitat ("diversity"), timber, and water provision.

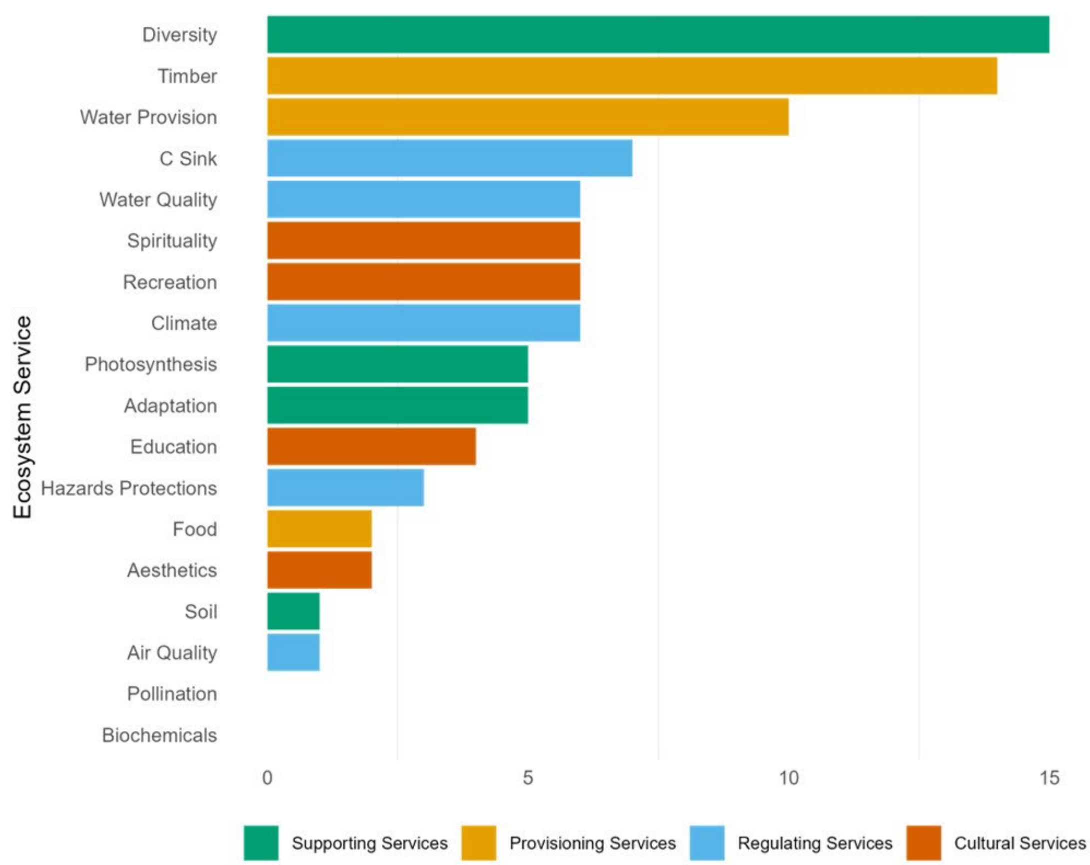

Figure 7.1. Priority ES identified by NCASI Member Companies with operations in Canada, based on responses (n = 16) to a questionnaire distributed in April 2024.

The following sections explore potential trade-offs that may emerge among these ES during CSF implementation. Some are supported by recent scientific literature, while others reflect anticipated challenges based on earlier research into ES under SFM, preceding the formalization of the CSF framework (Figure 7.2).

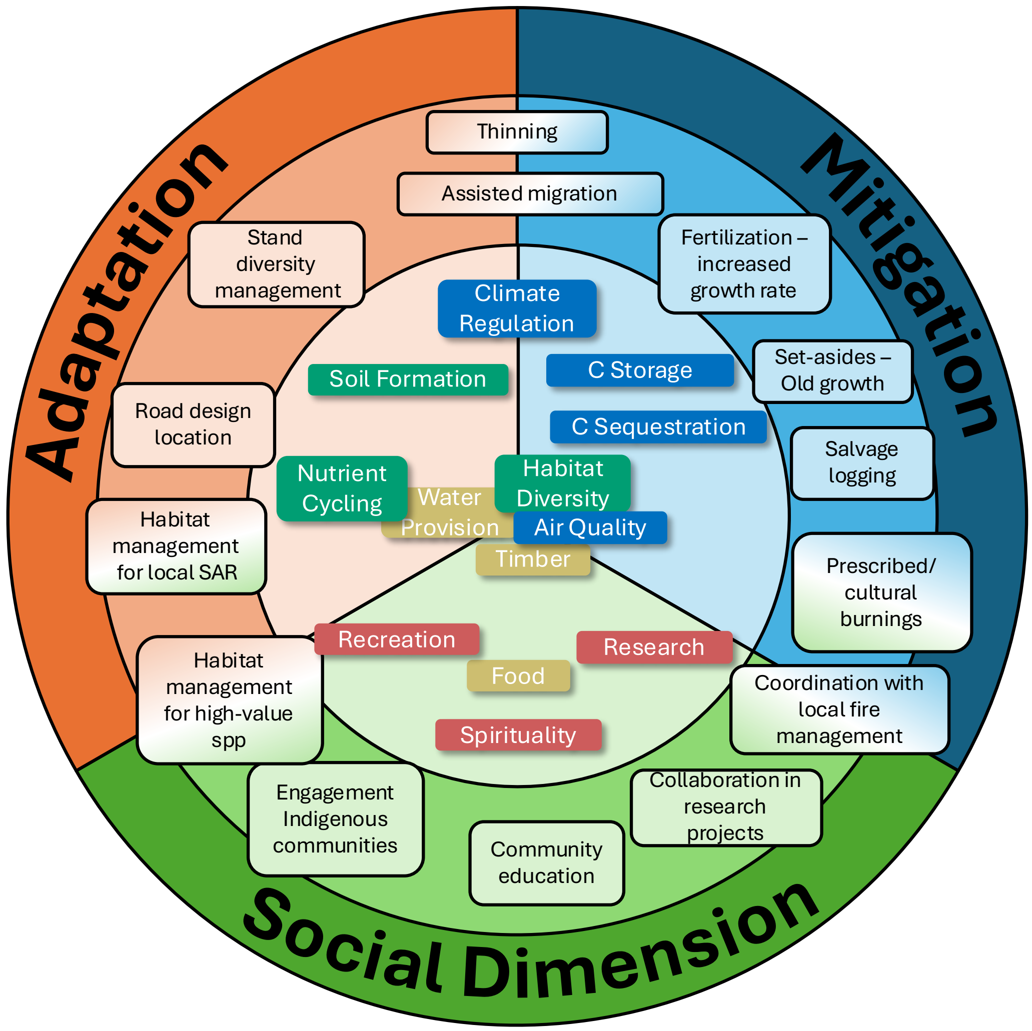

Figure 7.2. Interconnections among CSF components (outer circle), forest management strategies (middle circle), and ES (inner circle).
[Note: The overlapping and interrelated nature of these elements highlights the complexity of identifying optimal CSF practices that simultaneously achieve CSF objectives and deliver desired ES outcomes while minimizing potential trade-offs]

7.1 Adaptation vs. Mitigation

7.1.1 *Ecosystem Vulnerability (Adaptation) vs. Carbon Storage (Mitigation)*

A well-documented trade-off within the CSF framework is the balancing of ecosystem resilience (adaptation) and maximizing of carbon storage (mitigation) (Reyer et al. 2009). Fire suppression policies, historically intended to protect timber and carbon stocks, have led to the accumulation of dense forest biomass. While this increases short-term carbon storage, it simultaneously raises ecosystem vulnerability by creating excessive fuel loads that heighten the risk of severe, stand-replacing wildfires (Figure 7.3).

These risks are further exacerbated under a changing climate. Warming temperatures, prolonged droughts, and shifting precipitation patterns not only intensify fire behaviour but also reduce post-disturbance regeneration capacity in many regions. As documented (Boulanger et al. 2024; Jain et al. 2024; Stevens-Rumann et al. 2022), climate-driven disturbances, especially fire, are increasingly compromising forest recovery, threatening long-term forest stability, biodiversity, and carbon permanence.

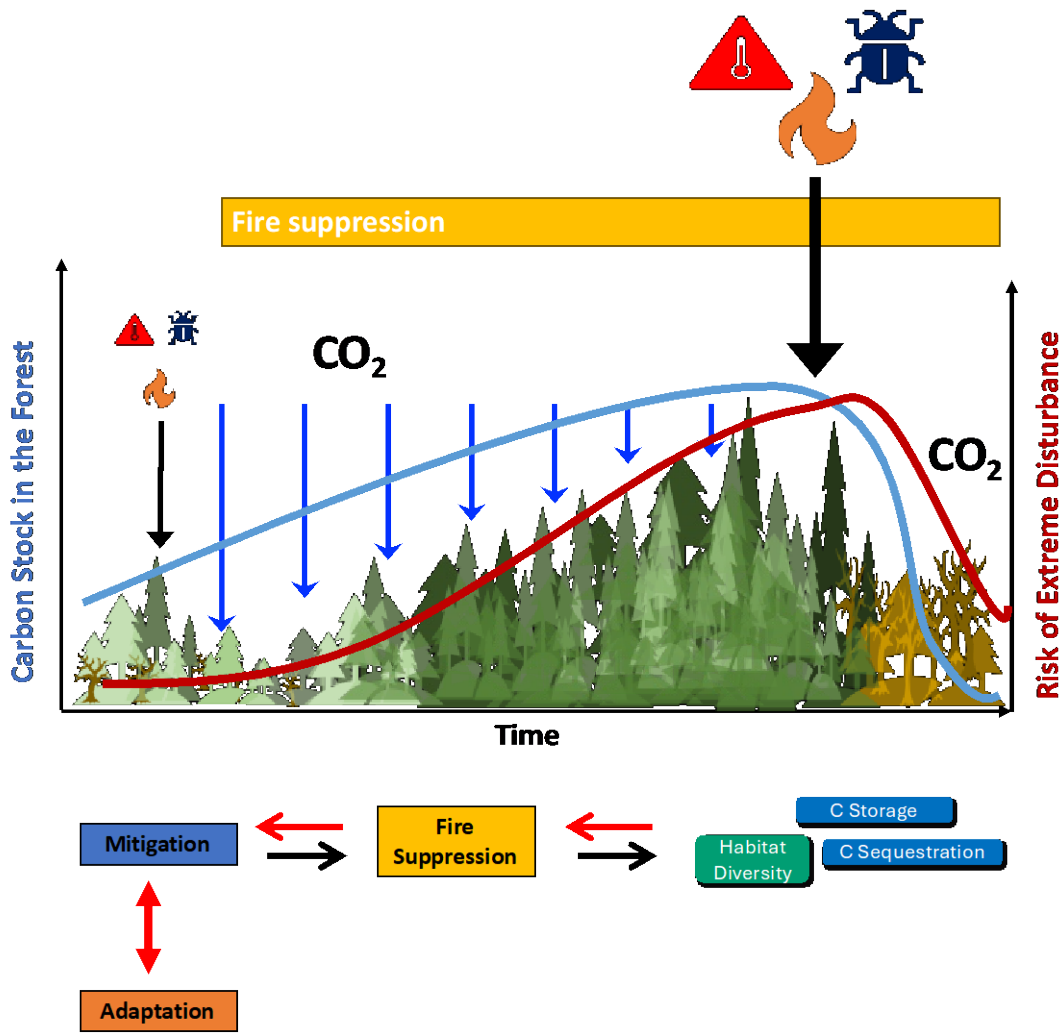

Figure 7.3. A trade-off between adaptation and mitigation in CSF: Fire suppression increases forest carbon storage (blue curve) in the short term but also raises disturbance risk (red curve) over time due to fuel buildup and aging stand vulnerability—initially, mixed-age forests are more resilient but store less carbon; over time, carbon accumulates, but so does the risk of wildfire and pest outbreaks, highlighting the tension between maximizing carbon and maintaining ecosystem resilience.

7.2 Adaptation vs. Social Dimension

7.2.1 *Diversified Reforestation (Adaptation) vs. Timber Harvesting (Social)*

Managing for high timber yields often involves shorter rotation periods and simplified stand structures, which can limit or prohibit the development of old-growth features needed for habitat provision (e.g., presence of coarse woody debris, snags). In contrast, strategies that promote long-term ecosystem resilience, such as extending rotations and increasing tree species diversity, may reduce short-term economic returns (Figure 7.4).

Tree species diversity has been shown to enhance forest resistance to pests, pathogens, and climate extremes, while also supporting a broader range of biodiversity and ES (Messier et al. 2022). This resilience, sometimes described as the "Jack-of-all-trades" effect, illustrates how structurally and functionally diverse forests can better buffer against global change (Messier et al. 2019). While monocultures are economically efficient in the near term, they are typically more vulnerable to large-scale disturbances. To improve resilience, forest managers are increasingly turning to functional traits, such as wood density, shade tolerance, drought tolerance, and resprouting ability, rather than relying solely on species richness. Grouping species based on these traits can enhance both ecological stability and functional diversity (Messier et al. 2019; 2022).

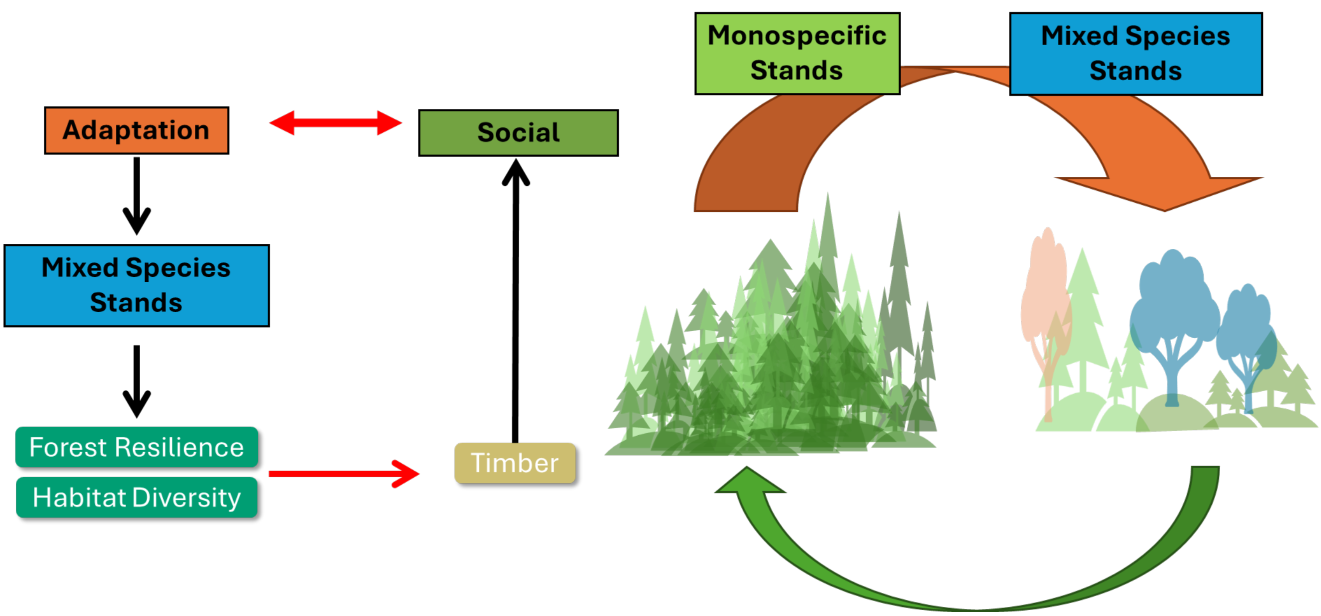

Figure 7.4. Example of an ecosystem service trade-off between the adaptation and social components of CSF: Management interventions such as thinning or incorporating broad-leafed species can enhance long-term forest resilience to climate-related disturbances; however, these strategies may temporarily reduce the commercial value of treated stands, illustrating the trade-off between building adaptive capacity and sustaining short-term economic returns

7.3 Mitigation vs. Social Dimension

7.3.1 *Carbon Storage (Mitigation) vs. Biodiversity Conservation (Social)*

Strategies that prioritize carbon sequestration, such as afforestation with fast-growing species, can conflict with the habitat needs of certain wildlife. Uniform, closed-canopy stands, often designed for carbon storage, tend to lack the structural diversity required by species that depend on early successional habitats.

This challenge is well illustrated in the Northeastern and Great Lakes region of the US, where efforts to enhance carbon storage have inadvertently reduced the suitable breeding habitat of the golden-winged warbler (*Vermivora chrysoptera*), a species listed as threatened in Canada since 2007 (Government of Canada 2025i). The warbler requires open, early seral forests for breeding, which are less common under carbon-optimized forest management (Figure 7.5). This example underscores the difficulty of achieving mitigation goals without compromising the ecological needs of sensitive species.

Habitat to be restored and maintained	Habitat quality for focal species	Stand-level carbon storage in trees	Habitat and wildlife species diversity	Risk of carbon release from severe disturbance	Enhanced resilience and adaptive capacity
Early successional n. hardwoods	↗	↘	↗	↘	↗
Tallgrass aspen parklands	↗	↘ *	↗	↘	↗
Oak savanna	↗	↘ *	↗	↘	↗
Pitch pine-scrub oak barrens	↗	↘	↗	↘	↗

Stand-level effects (Habitat quality for focal species; Stand-level carbon storage in trees) Landscape-level effects (Habitat and wildlife species diversity; Risk of carbon release from severe disturbance; Enhanced resilience and adaptive capacity)

Figure 7.5. Likely stand-level and landscape-level effects of restoring or maintaining habitat conditions for focal species in four case studies evaluated in Littlefield et al. (2022). [Note: Purple arrows represent likely positive effects; orange arrows indicate likely negative effects; asterisks indicate cases in which soil carbon may increase over the long term as native grasses and other herbaceous vegetation reestablish, despite a decrease in stand-level carbon storage in trees] [*Source*: Adopted from Littlefield et al. (2022)]

Managing habitat for species with contrasting ecological requirements often involves difficult trade-offs. For example, moose (*Alces alces*) thrive in early-successional forests, which provide critical forage and habitat. Beyond their ecological role, moose are a culturally and nutritionally important species for many Indigenous communities, forming part of traditional subsistence practices and food sovereignty. By contrast, woodland caribou (*Rangifer tarandus*), a conservation priority under Canadian policy (NCASI 2020a), also utilize certain features of early seral stages, particularly forage resources that are critical in their non-winter diets (Denryter et al. 2017). However, caribou persistence ultimately depends on extensive tracts of old forests that provide refuge from predation. Balancing these divergent requirements calls for spatially nuanced and policy-informed planning that both respects Indigenous Peoples rights and fulfills conservation obligations, ensuring that one priority is not advanced at the expense of another (Figure 7.6).

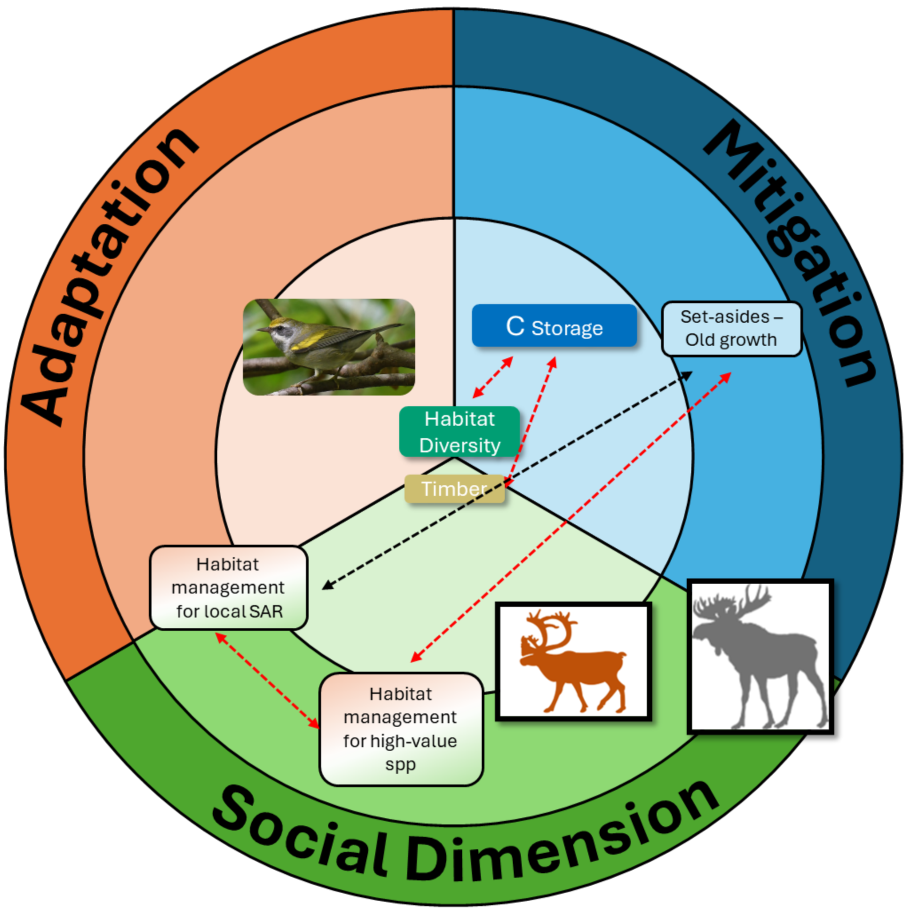

Figure 7.6. Trade-offs between mitigation and social dimension components of CSF: Allocating forest areas solely for carbon storage can reduce timber supply and habitat availability for culturally significant species like moose, while benefiting species reliant on older forest conditions, highlighting the complex interplay between biodiversity, cultural values, and climate goals.

7.3.2 *Carbon Storage (Mitigation) vs. Timber Harvesting (Social)*

Increasing the area of unmanaged or set-aside forest to store carbon can reduce timber availability, creating tensions between climate mitigation goals and socio-economic outcomes. Studies consistently show that prioritizing scenarios for carbon storage reduces timber yields (Gregor et al. 2022; Gutsch et al. 2018; Mazziotta et al. 2022; Schwaiger et al. 2019). For example, Gutsch et al. (2018) found a 30% decline in timber production in their "nature protection" scenarios (i.e., their carbon-centric scenario modelling higher biomass stock and longer rotation cycles), a reduction equivalent to a 0.65 t C ha^{-1} y^{-1}, compared to high-harvest biomass production strategies. Similarly, Duncker et al. (2012) reported that unmanaged forests retain higher carbon stocks in living biomass than managed forests.

Notably, many ES interaction studies do not account for the carbon stored in harvested wood products or the substitution effect, where wood-based materials replace more carbon-intensive alternatives (Duncker et al. 2012). Wood products can have particularly strong benefits, especially in construction. A recent literature review found that the embodied GHG emissions of wooden buildings are, on average, one-third to one-half those of conventional buildings (Andersen et al. 2021; Taylor et al. 2023). Life-cycle analyses further show that harvesting, when substitution and displacement are considered, can reduce net emissions by providing long-lived wood products with lower embodied carbon (Sathre et al. 2010; Smyth et al. 2017).

At the end of their useful life, wood and paper products can continue to provide long-term carbon storage, depending on how they are managed. Between 15% and 90% of carbon in landfilled wood and paper may remain stored long term (NCASI 2021a). Skog (2008) estimated that about two-thirds of discarded wood is landfilled, where 77% of that carbon remains stored indefinitely. Further, for paper products, one-third of discarded paper is landfilled, with 44% not subject to decay (Skog 2008). Similarly, Smith et al. (2006) reported that approximately 40% of carbon in softwood lumber and plywood remains stored in products in use or in landfills for a century after production.

Taken together, these findings suggest that timber harvesting is not necessarily in conflict with climate goals when product longevity, end-of-life fate, and substitution effects are factored in (NCASI 2020b; 2021a). Accurate carbon modelling, therefore, requires integrating sequestration dynamics, storage pools, market-driven substitution and leakage, and disturbance risks (NCASI 2020b). Ultimately, forest management decisions critically influence the balance between emissions and removals, underscoring the need for refined models that capture the full carbon cycle and its interaction with diverse forest management strategies.

8.0 MOVING FORWARD

The Canadian forest sector operates within a complex landscape shaped by diverse geographic, regulatory, and socio-economic contexts. While this diversity presents challenges to the streamlined implementation of CSF, it also creates opportunities for innovation, resilience, and transformation under a changing global climate.

8.1 Barriers and Hurdles

Despite the potential to enhance forest resilience and carbon storage, the widespread adoption of CSF in Canada remains limited. Institutional fragmentation, regulatory rigidity, and economic constraints continue to impede progress. These challenges, long recognized in the literature (Antwi et al. 2024b; Messier 2015), were echoed in responses to NCASI's 2024 survey of Canadian Member Companies (Figure 8.1), in which most respondents identified institutional and logistical barriers as the primary obstacles to CSF adoption.

The alignment between NCASI Member feedback and existing research underscores why CSF remains under-reported and under-implemented. These persistent barriers help explain the slow uptake of climate-responsive forest management practices and the lack of a formal accountability framework (Figure 8.2).

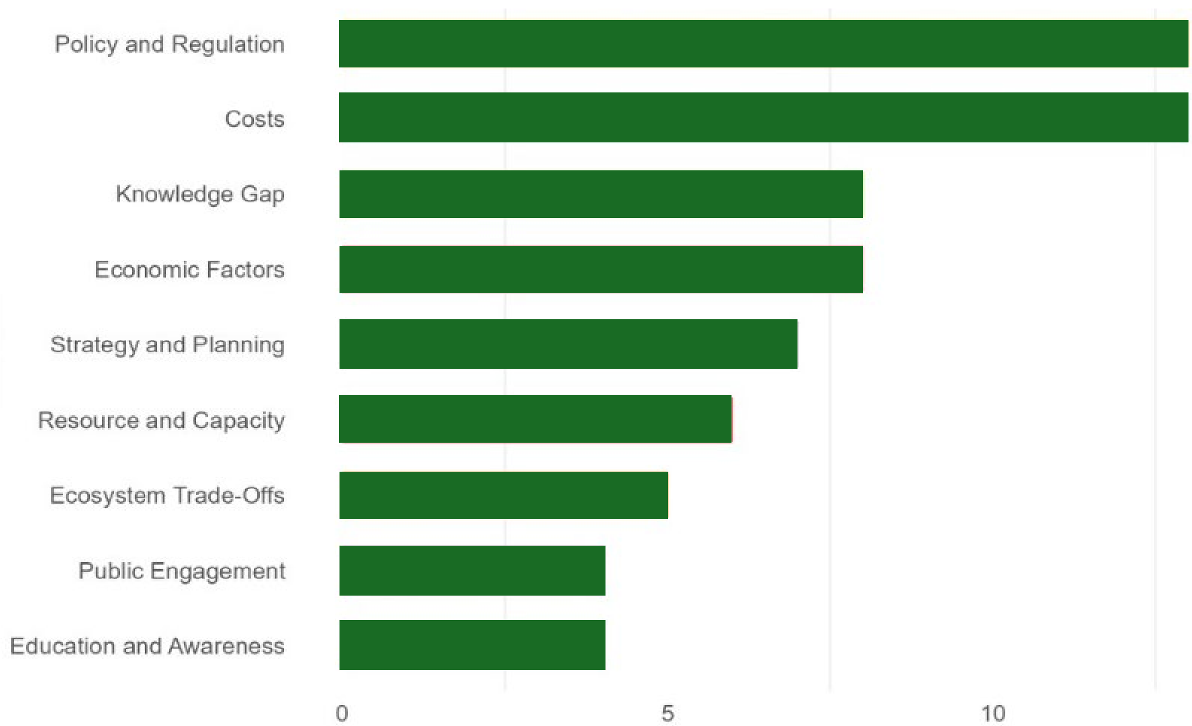

Figure 8.1. Barriers to CSF implementation identified by NCASI Canadian Member Companies based on responses (n = 16) from a questionnaire distributed in April 2024.

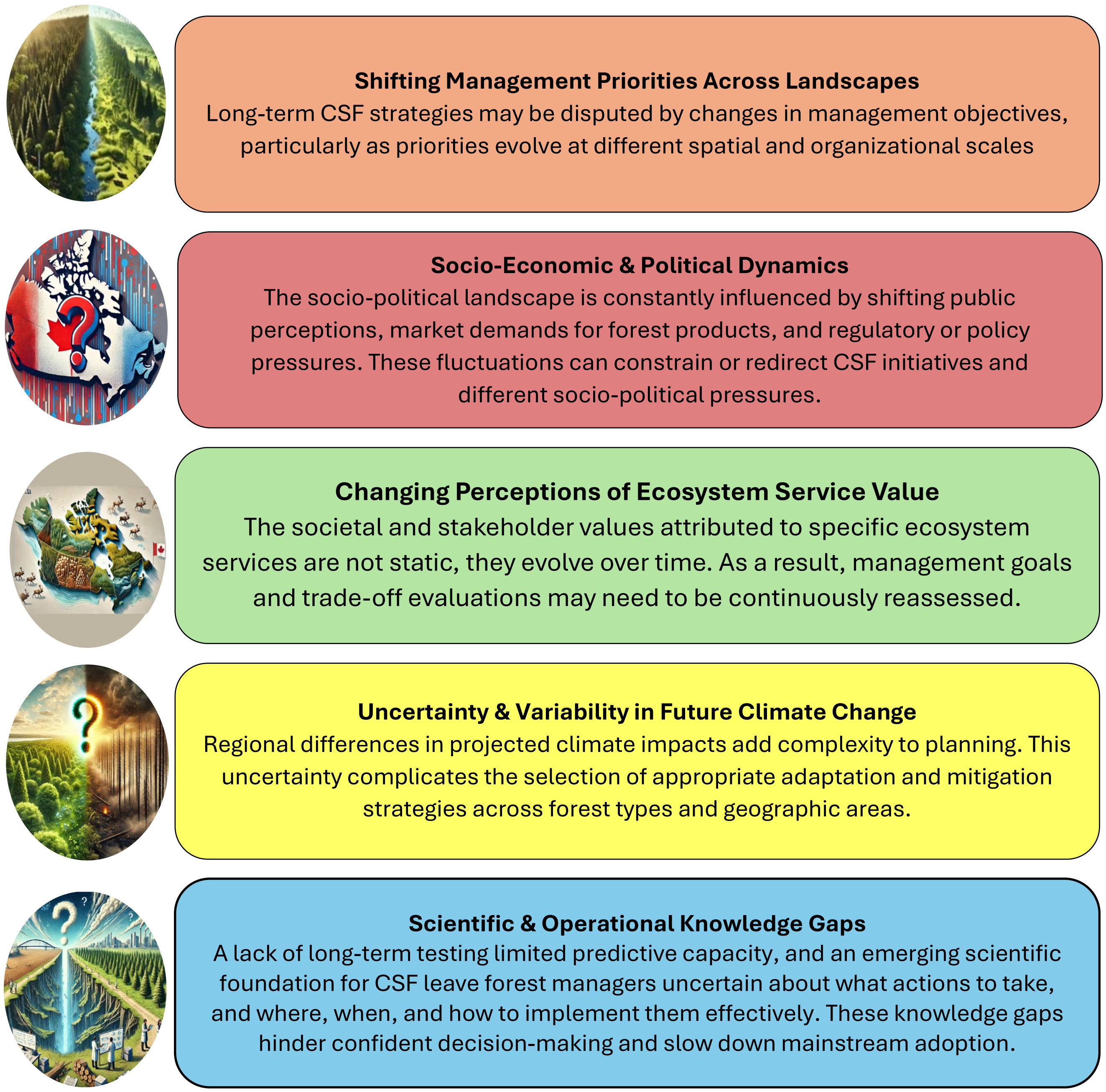

Figure 8.2. Five interrelated sources of uncertainties that complicate the long-term strategic planning and implementation of CSF include the variability in management priorities, socio-economic and political dynamics, shifting values attributed to ecosystem services, uncertainty about future climate change impacts, and limited evidence on the long-term outcomes of untested CSF strategies.

8.1.1 *Policy and Regulation*

As with SFM, policy and regulatory frameworks form the foundation of CSF, determining which practices are permitted, promoted, or restricted. However, in Canada, these frameworks often remain siloed and fragmented, limiting the flexibility needed for adaptive, climate-responsive management (Antwi et al. 2024b; Williamson et al. 2017).

Institutional complexity, such as overlapping jurisdictional mandates, rigid tenure systems, and inconsistent funding mechanisms can constrain policy innovation and delay the adoption of adaptive measures (Ameztegui et al. 2018; Hotte et al. 2016). Additionally, perceptions of climate change and its urgency vary widely across regions and institutions, reinforcing the need for region-specific strategies and governance models that are participatory and inclusive (Ameztegui et al. 2018; Hallberg-Sramek et al. 2022; Messier 2015).

Participatory governance frameworks that engage policymakers, forest managers, Indigenous communities, and local stakeholders are critical. These models encourage co-development of solutions, foster social license, and ensure that climate-responsive strategies are locally relevant and politically feasible (Hallberg-Sramek et al. 2022). Without such integrated and adaptive approaches, regulatory inertia will continue to impede CSF progress.

8.1.2 *Resource and Capacity Limitations*

Implementing CSF can be hampered by practical resource constraints, including limited skilled personnel, inconsistent access to high-quality data, and a lack of user-friendly decision-support tools (Nelson et al. 2016; Puettmann et al. 2015). Stakeholders consistently emphasize the need for integrated monitoring systems, regionally tailored datasets, and intuitive indicators to help fill persistent knowledge gaps and guide site-specific decision-making (Ameztegui et al. 2018; Hallberg-Sramek et al. 2022).

Economic challenges further complicate implementation. The upfront costs associated with adaptive practices, such as sourcing climate-resilient seed stock, cultivating new species, and replanting, can delay financial returns. These uncertainties are compounded by unclear market demand for novel or new species timber products, which are often less established than conventional options (Puettmann et al. 2015; Shephard et al. 2023). In addition, broader macroeconomic pressures, including timber market volatility, limited availability of qualified contractors, and uneven access to financial incentives, also shape forest management decisions and influence the pace and scale of CSF adoption (Ameztegui et al. 2018; Shephard et al. 2023).

8.1.3 *Educational and Engagement Gaps*

Legacy forestry education and engrained management paradigms often contribute to skepticism toward CSF approaches (Puettmann et al. 2015). The ecological, economic, and long-term benefits of climate-responsive practices can be emphasized through targeted training for foresters, policymakers, and local communities, to help facilitate a cultural shift (Schmitt et al. 2021). Broader public engagement and inclusive, participatory decision-making processes can build social license and foster collaborative forest stewardship (Andrews-Key et al. 2025; Halofsky et al. 2018).

Significant disparities in climate awareness among Canadian forestry professionals highlight the need for regionally customized education and capacity-building programs (Ameztegui et al. 2018). These efforts can also incorporate local and Indigenous knowledge to enhance ecological insight and bridge gaps in site-specific decision-making (Nelson et al. 2016).

Compounding these challenges is limited access to timely, relevant information. Forest managers often struggle to obtain or apply data due to inconsistent availability across regions, incompatible formats, or a lack of user-friendly models (Price et al. 2019; Halofski et al. 2018). Many decision-support tools remain in development or have yet to fully integrate future climate projections (Nelson et al. 2016). Gaps in future timber supply forecasts and uncertainties around forest response to management interventions, shaped by soil species composition and local climate, further complicate implementation (Andrews-Key et al. 2025; Shannon et al. 2019).

Addressing these knowledge and engagement barriers will require coordinated investment from governments, academia, and the forest industry to improve data accessibility, build adaptive capacity, and foster a shared understanding of CSF objectives (Williamson et al. 2017).

8.2 Avenues to Reduce Uncertainty

Despite persistent barriers and uncertainties surrounding future climate impacts, CSF is transitioning from a theoretical framework to an operational reality in Canada (Nabuurs et al. 2017; Yousefpour et al. 2018). A growing number of research initiatives and emerging technologies are helping bridge the knowledge gap, supporting integration into forest management. Key advances are outlined below.

8.2.1 *Modelling, Prediction, and Scenario Analysis*

Effective CSF decision-making requires tools that can evaluate trade-offs among carbon storage, biodiversity, and timber production. Muys et al. (2023) emphasize that robust modelling frameworks are essential to supporting informed and balanced strategies.

Several tools already support these efforts. British Columbia's Climate-Based Seed Transfer system aligns seed sourcing with projected climate conditions and is being used in operational reforestation planning (see section 4.2.1, O'Neill et al. 2017). Similarly, the Climate Change Informed Species Selection tool assists in selecting tree species best suited to future climates (MacKenzie et al. 2021). Québec's DREAM (Desired Regeneration Assisted Migration) framework integrates climate-informed seed selection, predictive modelling, and field trials to refine species selection (Royo et al. 2023).

A review by Giuntoli et al. (2020) highlighted that the carbon benefits of forest bioenergy depend heavily on model assumptions, especially regarding additional biomass production. This underscores the importance of using transparent, inventory-informed models, backed by empirical data (Bosela et al. 2022), to guide treatment selection aligned with ecosystem function goals.

High-Precision Monitoring: SmartForests Canada

Model performance depends on reliable, high-quality data. The SmartForests initiative is building a national-scale monitoring network to improve climate response models (Pappas et al. 2022; Torresan et al. 2021). The network features over 100 precision plots across a 4,400-km environmental gradient (Figure 8.3), where the program supports the following:

1. A distributed network of high-resolution monitoring sites;
2. Multi-scale data synthesis on forest response to climate and disturbance;
3. Evidence-based inputs for growth models and policy decisions (Pappas et al. 2022).

Data collected span multiple scales, from plant tissues to landscapes, and include both automated and manual observations. Measured variables cover meteorology, soil moisture, nutrient cycling, root growth, tree physiology, phenology, and more (Pappas et al. 2022).

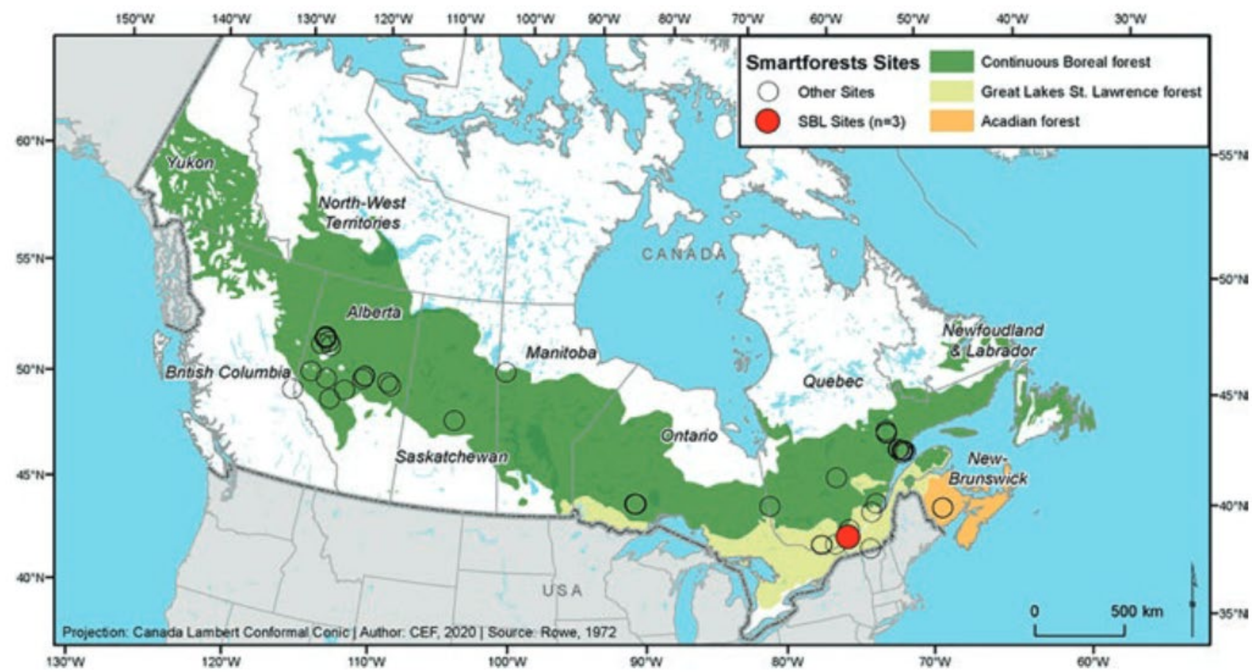

Figure 8.3. SmartForests Canada monitoring network spanning diverse gradients and forest types [*Source*: Adopted from Pappas et al. (2022)]

8.2.2 *In Situ Sensors and Remote Sensing*

Emerging technologies in environmental sensing are transforming how forest dynamics are tracked. In situ sensors such as dendrometers and sap-flow gauges monitor growth and water use in real time. Advanced tools like hyperspectral imaging and 3D tomography provide data on wood quality and forest structure (Torresan et al. 2021).

Sensor-linked data enable researchers to assess the effects of silviculture on ES delivery. Leaf temperature and isotopic composition offer insights into drought stress and forest productivity, revealing regional differences in evapotranspiration across Canada (Torresan et al. 2021).

Remote sensing, led by the Canadian Forest Service, plays a key role in large-scale monitoring (Torresan et al. 2021). The Earth Observation for Sustainable Development of Forests land cover map, derived from Landsat satellite imagery, supports SFM and biomass reporting (Government of Canada 2025b). The SmartForests network integrates these satellite observations with ground-based measurements to model carbon dynamics, forest composition, and structure at high resolution (Pappas et al. 2022). Finally, Canadian startups are developing real-time, wireless sensor platforms that serve as early warning systems for disturbances. These innovations promise to enhance adaptive forest management and expand the national capacity for climate-smart decision-making (Appendix H).

9.0 CONCLUSION

Between 2017 and 2025, CSF has emerged internationally as a strategic framework for managing forests in the face of an accelerating changing climate. In Canada, CSF builds directly upon the foundations of SFM, expanding its scope by integrating explicit climate adaptation and mitigation objectives alongside the continued delivery of ecological, economic, and social benefits. Importantly, many of CSF’s core principles, such as biodiversity conservation, adaptive planning, and engagement with Indigenous communities, are already embedded within Canada’s forest management systems.

This legacy of SFM provides a strong platform for advancing CSF without the need for entirely new institutional structures. Instead, CSF can be realized by adapting and enhancing existing tools and strategies: refining vulnerability assessments, strengthening risk reduction approaches, and deepening Indigenous and stakeholder engagement. Rather than a whole transformation, CSF represents a strategic reframing of current practices to better respond to climate imperatives.

Of the three CSF components, adaptation, mitigation, and the social dimension, adaptation has emerged as the most immediate and actionable priority within Canada’s current forest management landscape. Mitigation remains critical, but its implementation is often less well defined, particularly in relation to balancing short- and long-term carbon goals. Meanwhile, the social dimension is uniquely important in Canada, where meaningful engagement with Indigenous Peoples is both a legal obligation and a pathway to more resilient and just forest stewardship. Case studies from Mistik and Mosaic demonstrate how Indigenous partnerships are already shaping CSF in practice.

Nevertheless, implementation challenges persist. Definitions of CSF vary, and the uneven emphasis placed on adaptation, mitigation, or social values creates inconsistency. Trade-offs between carbon storage and biodiversity, timber yields and long-term resilience, or adaptation and mitigation strategies, remain difficult to quantify and manage. Institutional fragmentation, economic constraints, and uncertainty about climate impacts further complicate efforts to scale CSF nationally.

To address these challenges, emerging tools such as multi-criteria decision support systems and landscape-level planning frameworks offer promising pathways. These approaches help operationalize CSF by allowing forest managers to evaluate complex trade-offs and make transparent, evidence-based decisions. Still, more work is needed to standardize definitions, improve coordination across jurisdictions, and expand the evidence base on ES trade-offs in the Canadian context.

Ultimately, CSF should not be seen as a departure from SFM but as its evolution, a forward-looking framework that enhances forest resilience, strengthens climate mitigation, and embraces diverse values and knowledge systems. As climate and societal pressure intensify, CSF offers Canada a pragmatic, flexible, and science-informed path toward forest management that is not only sustainable but also climate-ready and socially inclusive.

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Appendix A

Main Third-Party Forest Certification Organizations That Operate in Canada and Their Associated Standards, Criteria, and Principles Linked to Climate-Smart Forestry Components

[Note: PEFC is an alliance of forest certification systems operating through the recognition of other third-party forest certification organizations]

Third-Party Organization	Standards		Details	Associated Climate-Smart Forestry Component
Sustainable Forestry Initiative (SFI)	Objective 2 Forest Health and Productivity	2.1 (Reforestation)	2.1.1. Document reforestation plans. 2.1.2. Use adequate criteria to assess regeneration and correct actions. 2.1.3. Prefer use of native or non-invasive species. 2.1.4. Protect natural regeneration sources.	A&M
		2.4 (Protect against disturbances)	2.4.1. Protect forests from damaging agents (wildfire, pests, diseases, invasive species). 2.4.2. Promote healthy and productive forests to reduce susceptibility. 2.4.3. Promote fire and pest prevention and control programs.	A&M
		2.5 (Seedlings)	2.5.1. Research, test, evaluate, and deploy improved planting stocks.	A
	Objective 5 Visual Quality and Recreational Benefits	5.1 (Visual quality)	5.1.1. Address visual quality management. 5.1.2. Consider aesthetics in harvesting, road, landing designs, and management.	S
		5.4 (Recreation)	5.4.1. Provide recreational opportunities for the public.	S
	Objective 6 Protection of Special Sites	6.1 (Special sites)	6.1.1. Identify natural heritage for protection with expert advice, stakeholders, and Indigenous Peoples. 6.1.2. Map, catalogue, and manage special sites.	S
	Objective 9 Climate-Smart Forestry	9.1 (Adaptation)	9.1.1. Identify and prioritize climate risk based on likelihood, nature, and severity. 9.1.2. Conduct adaptation planning. 9.1.3. Align with regional strategies. 9.1.4. Conduct annual reporting on progress toward adaptation goals.	A
		9.2 (Mitigation)	9.2.1. Optimize carbon sequestration. 9.2.2. Enhance ecosystem resilience. 9.2.3. Address greenhouse gas emissions with control programs. 9.2.4. Report annually on climate mitigation measures.	M
	Objective 10 Fire Resilience and Awareness	10.1 (Wildfire risk mitigation)	10.1.1. Assess wildfire risks and the role of fire in managed forests. 10.1.2. Manage to enhance forest resilience and reduce wildfire impacts. 10.1.3. Restore wildfire damage, protect soil and water, and support long-term forest recovery.	M
		10.2 (Collaborative fire stewardship)	10.2.1. Support fire prevention and management programs across jurisdictions. 10.2.2. Engage in programs promoting fire management benefits and raising awareness of fire risks to ecological and societal values.	M&S

	Objective 12 Forestry Research, Science and Technology	12.1. (Support forest research)	12.1.1. Ensure financial or in-kind support of research, collaborations, or knowledge transfer. 12.1.2. Ensure knowledge gained through research is shared.	S
		12.2. (Use of regional analyses)	12.2.1. Participate in the development of information in a variety of topics.	S
	Objective 13 Training and Education	13.2 (Professionalism and training)	13.2.1. Support the development of core training programs for logging professionals. 13.2.2. Promote their continued education in a variety of topics.	S
Forest Stewardship Council (FSC)	Principle 3 Indigenous Rights	–	3.1. Identify Indigenous Peoples in or affected by the management area and their rights. 3.2. Respect their rights to control forest activities that affect their lands. 3.3. Secure a binding agreement with Free, Prior, and Informed Consent. 3.4. Uphold Indigenous rights, customs, and cultures as outlined in United Nations Declaration on the Rights of Indigenous Peoples and International Labour Organization Convention 169. 3.5. Identify and protect culturally significant sites in collaboration with Indigenous Peoples. 3.6. Protect and compensate for the use of Indigenous traditional knowledge through agreements.	S
	Principle 4 Community Relations	–	4.3. Provide fair opportunities for employment, training, and services to local communities. 4.4. Support social and economic development. 4.5. Identify, avoid, and mitigate significant negative impacts on communities. 4.6. Establish grievance mechanisms for adverse impacts from management activities. 4.7. Protect culturally significant sites through agreements.	S
	Principle 6 Environmental Values and Impacts	–	6.8. Maintain and restore a mosaic of species, sizes, and ages spatial scales and regeneration cycles that enhance environmental (and economic) resilience.	A
	Principle 10 Implementation of Management Activities	–	10.1. Ensure natural or artificial regeneration of forests. 10.2. Use ecologically well-adapted species. 10.9. Assess risk, and implement activities that reduce negative impacts from natural hazards.	A&M
Programme for the Endorsement of Forest Certification (PEFC)	Criterion 1 Biological Diversity	1.1. (Ecosystem diversity)	Conserve ecosystem diversity at the stand and landscape levels by maintaining a variety of communities naturally occurring.	A&M
		1.4. (Sites of special significance)	Respect protected areas designated by government authorities. Collaborate on landscape-level management involving protected and significant sites. Identify and manage biologically, geologically, or culturally significant sites to ensure their long-term conservation.	S

	Criterion 2 Ecosystem Condition and Productivity	2.1 (Ecosystem productivity)	Focus on the impacts of climate change on forests and how forests might be managed to adapt to the changes. Conserve forest ecosystem productivity and productive capacity by maintaining ecosystem conditions that are capable of supporting naturally occurring species. Reforest promptly, and use tree species ecologically suited to the site	A
	Criterion 4 Role in Global Ecological Cycles	4.1 (Carbon uptake and storage)	Maintain the processes that take carbon from the atmosphere and store it in forest ecosystems. 4.1.1. Monitor net carbon uptake. 4.1.2. Work toward reforestation success.	M
		4.2 (Forest conversion and afforestation)	Protect forests from deforestation. Encourage afforestation where ecologically appropriate.	M
	Criterion 5 Economic and Social Benefits	5.2 (Communities and sustainability)	Contribute to the sustainability of communities by providing opportunities to derive benefits from forests and by supporting local community economies.	S
	Criterion 7 Indigenous Relations	7.1 (Treaty rights)	Recognize and respect Aboriginal title and rights, and treaty rights.	S
		7.2 (Forest values, knowledge and uses)	Respect Indigenous forest values, knowledge, and uses as identified through an Indigenous input process.	S

[Note: A = Adaptation; M = Mitigation; S = Social]

Appendix B
Climate-Smart Forestry Definitions Given in the Scientific Literature Up To January 2025
[Note: Non-exhaustive list]

Year	Geographic Context	Definition	Reference
2008	Canada	"The climate smart management framework is rooted in the use of existing forest management practices to reduce the risk from the impacts of natural and anthropogenic disturbances and to promote or maintain ecological resilience under climate change"	(Nitschke et al. 2008)
2020	Europe	"CSF is sustainable adaptive forest management and governance to protect and enhance the potential of forest to adapt to and mitigate climate change. The aim is to sustain ecosystem integrity and functions and to ensure the continuous delivery of ecosystem goods and services, while minimising the impact of climate-induced changes on mountain forests on well-being and nature's contribution to people."	(Bowditch et al. 2020)
2020	Global	"CSF aims to connect mitigation with adaption measures, enhance the resilience of forest resources and ecosystem services, and meet the needs of a growing population and expanding middle class. CSF has been introduced as a holistic approach to guide forest management in Europe (Nabuurs et al., 2017; Jandl et al., 2018; Yousefpour et al., 2018), but the approach is of global relevance (e.g., Bele et al., 2015). CSF builds on the concepts of sustainable forest management, with a strong focus on climate and ecosystem services."	(Verkerk et al. 2020)
2021	Global	"Climate-smart forestry explicitly integrates the challenges and opportunities of climate change into forest policy, planning and practices."	(FAO 2021)
2021	Europe	Cites Bowditch et al. (2020): "Climate-Smart Forestry is a sustainable adaptive forest management and governance to protect and enhance the potential of forest to adapt to and mitigate climate change. The aim is to sustain ecosystem integrity and functions and to ensure the continuous delivery of ecosystem goods and services, while minimizing the impact of climate-induced changes on mountain forests on well-being and nature's contribution to people. In summary, Climate-Smart Forestry should enable both forests and society to transform, adapt to and mitigate climate induced changes."	(Kašanin-Grubin et al. 2021)
2021	Europe	"Innovative management strategies to adapt and mitigate climate change and benefit forest production"	(Santopuoli et al. 2021)
2021	Global	"Climate-smart forestry (CSF) is an emerging branch of sustainable adaptive forest management aimed at enhancing the potential of forests to adapt to and mitigate climate change. Climate-smart forestry (CSF) aims to validate, promote, and deliver the climate-stabilizing benefits of forests on the temperature of the atmosphere consistent with the recommendations set out by the Paris Agreement (UNFCCC 2015)."	(Torresan et al. 2021)

2022	Europe	“The holistic approach of jointly considering adaptation, mitigation and ecosystem services in forest management.”	(Gregor et al. 2022)
2022	Europe	“stakeholders framed climate-smart forestry as active and diverse management towards multiple goals. It aims to integrate both climate adaptation and mitigation to protect and enhance nature's multiple contributions to people and increase forests' contributions to global agendas”	(Hallberg-Sramek et al. 2022)
2022	US	“Timber industry, world leaders, non-governmental organizations, and non-industrial private forest landowners have acknowledged a synergistic relationship between economic goals and ecosystem services and have labeled it ‘Climate Smart Forestry’ (CSF).”	(Shephard et al. 2022)
2022	Europe	“Climate-smart forestry is sustainable adaptive forest management and governance to protect and enhance the potential of forests to adapt to and mitigate climate change. The aim is to sustain ecosystem integrity and functions and to ensure the continuous delivery of ecosystem goods and services, while minimising the impact of climate-induce changes on forest on well-being and nature's contribution to people.”	(Tognetti et al. 2022)
2023	Europe	“Nature-based solution integrating climate mitigation goals with adaptation measures to enhance the resilience of forest resources.”	(Muys et al. 2023)
2023	US	“CSF is a targeted, long-term strategy to enhance the climate benefits from forests and the forest products sector while providing sustainable resources for a growing human population.”	(Papa et al. 2023)
2023	US	“Broadly, CSF is a strategy to combat climate change effects with ongoing and innovative forestry practices.”	(Shephard et al. 2023)
2023	Global	“CSF is an emerging branch of sustainable forest management. The overall objective is to manage forests in response to climate change by promoting forest growth, increasing carbon sequestration and reducing carbon emissions from non-renewable resources. The CSF approach uses adaptive management to increase the forests' resilience to a range of climate change scenarios and climate-induced disturbances.”	(Triviño et al. 2023)
2025	Global	"Climate-Smart Forestry as an emerging concept in sustainable forest management, which develops innovative forest management and decision-making systems through the latest technologies like information technology and AI to address climate change challenges, aiming to enhance the resilience of forest ecosystems, improve their capacity to mitigate climate change while maintaining forest productivity and other ecosystem services, and ultimately achieve harmonious development between humans and nature."	(Wang et al. 2025)
2025	Global	"CSF is a set of comprehensive management strategies designed to address the challenges posed by climate change on forest ecosystems and resource management. These approaches integrate economic, social, and environmental considerations to alleviate the global threats of climate change, with its objective being to augment the resistance, recovery, adaptability, and productivity of these ecosystems while simultaneously mitigating the effects of climate change."	(Xie et al. 2025)

Appendix C

Summary of Objectives and Practical Steps for Conducting a Climate Vulnerability Assessment and Integrating Adaptation in Forestry Operations: Each Step Corresponds to a Worksheet in Edwards et al. (2015)

[Source: Adapted from Edwards et al. (2015); Andrews-Key et al. (2025)]

Stage	Purpose of the Stage	Step in Edwards et al. (2015)	Step Description in Edwards et al. (2015)	Associated Practical Steps	Mistik's Results Andrews-Key et al. (2025) (Non-Exhaustive)
1. Organizational readiness	To assess whether an organization is prepared to engage in a Climate Vulnerability Assessment (CVA) process. Ensures that the organization is both willing and able to carry out a CVA and act on the results. Good indicators of readiness are the pre-existence of work in climate issues at the company, a history of collaborations with scientific organizations around adaptation or mitigation of climate change, being at the beginning of a 20-year forest management plan renewal process, or simply willingness or support from leadership position to tackle the process (Andrews-Key et al. 2021; 2025)	—	—	—	1. The window of opportunity (FMP renewal) allowed Mistik to allocate staff and resources 2. Previous climate change work done for their 2007 FMP 3. Strong support from senior management, parent companies, the provincial government and the public advisory group 4. A pre-existing culture of collaboration and learning
2. Pre-VA	To establish a foundational understanding of the system, current climatic conditions, and the context for assessing future vulnerabilities. Sets the scope and context for the assessment. Helps identify key vulnerabilities to investigate more deeply in the next step and provides a shared understanding among stakeholders	1. Provide context for VA	Provides guidance for how to begin assessing vulnerability to climate change and mainstreaming adaptation into SFM. The focus is to develop an understanding of the need to address climate change and thus undertake an SFM VA, and to clearly define the goals of the assessment	Define the problem or challenge	
				Describe the SFM system and define the scope of the VA	
				Confirm the scope of the VA	
		2. Current climate and forest conditions	Provides guidance on describing and documenting how climate has shaped current forest conditions and management practices in	Describe climatic conditions and trends	1. Extreme weather (storms, temperature fluctuations, droughts) 2. Pests and disease outbreaks (e.g., dwarf mistletoe, pine beetle)

			the user's SFM area. Also provides guidance on documenting any current adaptations to climate change that the user may already be practicing	Describe the relationships among climate, forest conditions, and forest management practices	1. Forest regeneration challenges
				Describe how recent climate trends or changes in forest conditions have led to changes in current management practices	1. Infrastructure vulnerability (e.g., road washouts from early thaws) 2. Operational disruptions (e.g., fewer frozen days for winter operations)
				Identify uncertainties and knowledge gaps	1. Uncertainty regarding the reliability and accuracy of climate model scenarios 2. Knowledge gaps around how to acquire equipment necessary for salvage harvesting in blowdown stands 3. Knowledge gap on suitable alternative uses for salvaged wood
		3. Future climate and forest impact scenarios	Provides guidance on developing and describing future climate and forest impact scenarios	Develop and describe future climate scenarios	
				Develop and describe forest impact scenarios	
3. Detailed CVA	To assess how vulnerable specific components of the system are to climate impacts and evaluate the system's capacity to adapt. This is the core analytical stage of the CVA. It pinpoints which parts of the system are most at risk and where adaptation is most urgently needed	4. Assess vulnerability	Provides guidance on evaluating and documenting SFM vulnerability to current climate and the range of future climate change scenarios	Assess current and future impacts on SFM	
				Evaluate adaptive capacity of the SFM system	
				Assess current and future vulnerability	
				Assess overall vulnerability	

				Decision point: is adaptation required?	Yes
4. Identify, implement, and monitor adaptation	To develop and prioritize adaptation options, implement them, and set up mechanisms for learning and improvement over time. Translates assessment into action. Also institutionalizes adaptation by making it a living part of planning and decision-making, rather than a one-time initiative	5. Adaptation options	Provides guidance on developing climate change adaptation options for SFM	Develop potential adaptation options for SFM objectives	
				Develop potential adaptation options for the overall SFM system of interest	
		6. Implementation and mainstream of adaptation	Provides guidance on implementing and mainstreaming adaptation for SFM	Prioritize adaptation options	
				Recommend priority adaptation options for implementation	
				Implement (mainstream) recommended adaptations	1. Annual reassessment of road conditions to enhance resilience 2. Pre-approved stockpile locations for flexibility in wood supply 3. Flexibility through buffers 4. Minimization of fragmentation of habitat
				Evaluate adaptation performance	1. Organizational learning leading to changes such as including observations in relevant SOP, or conductional annual reassessments of adaptation priorities and vulnerabilities related to their SFM objectives 2. New climate-related monitoring indicators, like days lost due to weather/fire

[Note: CC = climate change; FMP = forest management plan; SFM = sustainable forest management; SOP = Standard operating procedure ; VA = vulnerability assessment]

Appendix D

Thirty-Nine Indicators Identified in Hallberg-Sramek et al. (2022) for the Implementation of Climate-Smart Forestry

[Source: Adapted from table 3 in Hallberg-Sramek et al. (2022)]

Category	Indicator	Comments by Hallberg-Sramek et al. (2022)
SFM: Policies, institutions, and instruments	C.1 Institutional frameworks	
	C.2 Legal/regulatory framework	
	C.3 Financial and economic instruments	
	C.4 Information and communication	
SFM: C1—Forest resources and carbon cycles	1.1 Growing stock	
	1.2 Age structure/diameter distribution	
	1.3 Forest carbon	
SFM: C2—Forest ecosystem health and vitality	2.1 Forest damage	
SFM: C3—Productive functions of forests	3.1 Increment and fellings	
	3.2 Roundwood (include quality aspects)	Quality aspects should also be included
	3.3 Non-wood goods	
	3.4 Services	
	3.5 Forests under management plans	
SFM: C4—Biological diversity	4.1 Diversity of tree species	
	4.2 Regeneration (include clear-cut size)	Size of individual clear-cuts should also be included; also related to C6
	4.3 Naturalness	
	4.4 Introduced tree species	
	4.5 Deadwood	
	4.6 Forest fragmentation	
	4.7 Protected forests	
SFM: C6—Socio-economic functions	6.1 Forest holdings (include resident/non-resident owners)	Should also include the proportion of resident/non-resident forest owners
	6.2 Recreation in forests	
	6.3 Net revenue	
	6.4 Investments in forests and forestry	
	6.5 Forest sector workforce (broadly defined)	Should include forest sector in a broad sense, such as people employed in forest-related businesses other than the timber and pulp industry
	6.6 Wood consumption (include longevity)	
	6.7 Wood energy	Should include the longevity of the products consumed
Bowditch et al. 2020	Forestry	
Hallberg-Sramek et al. 2022	Active forest management	Active management practices to optimize the use of the forests
	Collaborations and networks	Collaborations and networks to promote forests' multiple use
	Knowledge and experiences	Local knowledge and experiences of different management alternatives
	Local value chains	Local value chains for forest products and services
	Management of ungulates	Management of ungulates to promote tree species diversity
	Taxation policies	Taxation policies that feed back to the local area from which the wood was harvested

[Note: SFM = sustainable forest management]

Appendix E

Non-Exhaustive List of Climate Change Adaptation Initiatives Identified as Being Applied in Canada in the Forest Sector

[Source: Adapted from Williamson et al. (2019)]

Category	Initiative	Province(s)	Institution(s)	Reference(s)
Research and assessment	Developing practitioner guides for climate change assessment and other tools to support adaptation planning	ON	CCFM, Ontario Centre for Climate Impacts and Adaptation Resources	(Edwards et al. 2015; Gleeson et al. 2011)
	Assessing vulnerability and climate impacts and using the results to identify, discuss, and possibly implement adaptation options	BC, SK, ON, QC, MB	—	(Williamson et al. 2019)
	Developing regional climate scenarios	—	Pacific Climate Impacts Consortium, OURANOS, ECCC	(Williamson et al. 2019)
	Undertaking or promoting applied research into impact modelling, impact assessment, and adaptation options	BC, ON, QC, SK	NRCan, various universities, Saskatchewan Research Council	(Williamson et al. 2019)
	Completing a major review of changing wildland fire science requirements	—	—	(Sankey 2018)
Organizational changes	Developing climate change strategies and adaptation action plans	BC, AB	—	(Williamson et al. 2019)
	Enhancing capacity by dedicating significant new resources to climate change adaptation	BC, ON, QC	—	(Williamson et al. 2019)
	Developing performance measures to monitor and evaluate adaptation progress	BC	—	(Williamson et al. 2019)
Policy, practices, and approaches	Identifying and implementing new techniques, policies, and approaches to reduce wildfire risk in communities located within or near flammable forests	—	FireSmart Programs in several jurisdictions	(Williamson et al. 2019)
	Reviewing, researching, and in some cases modifying seed transfer guidelines, regulations, and policies	BC, QC, AB	—	(Williamson et al. 2019)
	Modifying species deployment (e.g., larch in BC—*Larix occidentalis*)	BC	—	(Williamson et al. 2019)
	Conducting assisted migration trials	BC, AB, ON, QC	—	(Lu et al. 2024; Pedlar et al. 2011; Sáenz-Romero et al. 2020; Williamson et al. 2019)
	Promoting science, science-policy integration, and science management partnerships	BC	—	(Williamson et al. 2019)
Guidance and extension	Undertaking communications, education, and professional development initiatives	BC	Association of BC Forest Professionals	(Williamson et al. 2019)
	Organizing workshops with staff within agencies on climate change effects and adaptation initiatives underway within organizations	BC	BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development	(Williamson et al. 2019)
	Organizing knowledge exchange workshops about climate change	—	Canadian Institute of Forestry, Forestry Adaptation Community of Practice	(Williamson et al. 2019)

[Note: AB = Alberta; BC = British Columbia; MB = Manitoba; ON = Ontario; QC = Québec; SK = Saskatchewan]

Appendix F

Definitions for the Ecosystem Service Concept by a Range of Sources

Source	Term	Definition	Reference
Millennium Ecosystem Assessment (MA)	Ecosystem Services (ES)	The benefits people obtain from ecosystems.	(Millenium Ecosystem Assessment 2005)
Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)	Nature's Contributions to People (NCP)	The benefits people obtain from ecosystems. In the MA, ES could be divided into supporting, regulating, provisioning, and cultural. This classification, however, is superseded in IPBES assessments by the system used under "Nature's contributions to people." This is because IPBES recognizes that many services fit into more than one of the four categories. For example, food is both a provisioning service and, emphatically, a cultural service in many cultures.	(IPBES 2019)
Common International Classification of Ecosystem Services (CICES)	Ecosystem Services	Contributions that ecosystems make to human well-being, and as distinct from the goods and benefits that people subsequently derive from them.	(CICES 2024)
US EPA National Ecosystem Services Classification System (NESCS Plus)	Final Ecosystem Services (FES)	Final ES are specifically defined as the services from nature that are "directly [emphasis added] enjoyed, consumed, or used to yield human well-being" (Boyd et al. 2007). This separates them from ecosystem characteristics and processes that help produce final ecosystem goods.	(Newcomer-Johnson et al. 2020)
	Final Ecosystem Goods (FEG)	Natural scientists generally use "ecosystem services" as a term to cover both goods and services. Final ecosystem goods (FEGs, or ecological end-products [EEPs]) are the biophysical components of nature that humans directly use or appreciate in final ES. The NESCS Plus is useful for classifying both FEG and final ES. In a general way, the term *final ES* encompasses both the FEG and the final ES concepts.	

Appendix G

References on Ecosystem Services and Trade-Offs Across Land Uses and Industries: Publications Focusing on Forestry ES Are Shown in Blue Cells; Canadian-Based Forestry Studies Are Shown in Purple; and Other Canadian-Based Studies Are Shown in Orange

Download the Appendix G Excel file here: https://www.ncasi.org/resource/technical-bulletin-no-1097-climate-smart-forestry-characteristics-benefits-and-trade-offs

Appendix H

Canadian Companies Offering Monitoring Services or Next-Generation Technology Services

[Note: Non-exhaustive list]

[Source: Data from Tracxn (December 2024)]

Province	Company Name	Website—Overview	Description
AB	4pi Lab	http://site.4pilab.com/ Developer of AI-based wildfire detection system	The developer of an AI-based wildfire detection system. It uses a network of satellites that will map the entire earth every six hours to detect very small wildfires in real time.
AB	ISB (Infused SeedBall USA LLC)	https://www.infusedseedball.com/ Provider of infused seed ball for forest planting	ISB is a provider of infused seed ball for forest planting. It develops the seed using a pyrolysis kiln process that has a blend of topsoil, and optional natural nutrients. It also offers an aero-grid system that allows planting through a drone system, and its software offers a premeditated mapping system with traceability.
BC	3LOG	https://www.3log.com Provider of business solutions for timber management and wood product companies	3LOG is a technology company that provides business solutions for timber management and wood product companies. It offers various products that include Log Inventory and Management System (LIMS), “WeighWiz” for weight scaling, “LabWiz,” and “LoaderWiz.”
BC	Genesis Ai	https://www.genesisaicorp.com/ Provider of AI-powered natural resource and fire detection management solutions	Genesis AI is a provider of AI-powered natural resource and fire detection management solutions. The company offers technology solutions for transforming fire management. It offers SaaS-platform modules for ecosystem management.
BC	PEOPLE-ER	https://www.people-er.info/ Earth observation for ecosystem restoration	PEOPLE-ER offers earth observation tools for ecosystem restoration and monitoring. It takes an open data approach and utilizes cloud processing and machine learning to offer forest analytics. It provides vegetation, wetlands, and wasteland recovery and trends.
BC	Taking Root	http://takingroot.org Provider of forest reforestation and carbon offsets solutions	Taking Root is a provider of forest reforestation and carbon offsets solutions.
NB	Remsoft	https://remsoft.com Solutions for asset life cycle optimization through big data	Remsoft is a provider of land-use planning solutions. The company focuses on optimizing land assets in forestry, utilities, and resources through analytics. The company's operational planning solution enables organizations to schedule production, optimize fiber distribution and transportation options, and manage production and transportation capacity. The decision-support tools allow organizations to compare alternatives and optimize project plans.
ON	Flash Forest	https://flashforest.ca Provider of AI- and drone-based wildlife conservation and reforestation solutions	Flash Forest is a provider of AI- and drone-based wildlife conservation and reforestation solutions. It offers reforestation solutions post-wildfire by merging UAV, GIS, automation, and ecological science. It leverages drone and biological seed-pod technology to reforest post-wildfire areas.
ON	AmpliCam	https://www.amplicam.com/	AmpliCam is a provider of AI-based system for video surveillance solutions. It provides users with a company specializing in early wildfire detection and

		Provider of AI-based system for video surveillance solutions	monitoring using cutting-edge AI, machine learning, and computer vision solutions. Its system uses digital video cameras to scan forests 360 degrees, day and night, to detect and monitor wildfires.
	SkyForest	https://skyforest.io/ Provider of tools to import spatial data, combine multiple data layers, and generate wildfire-risk metrics across assets	SkyForest SaaS platform integrates high-resolution geospatial datasets with wildfire exposure models to help users quantify and visualize fire risk across their management areas.
	Sigma Eight	https://sigmaeight.ca Manufacturer of radio wildlife tracking equipment and systems	Sigma Eight is a manufacturer of radio wildlife tracking equipment and systems. They offer a range of radio transmitters, receivers, antennae, and applications that enable customers to track animals. These radio devices could be fitted to nearly any animal and could be customized to any shape and size. They have devices for tracking different animals including fish, birds, snakes, and turtles.
	FastPheno	https://www.fastpheno.com/ Provider of drone and phenotyping-based forest tree breeding services	FastPheno is a provider of drone and phenotyping-based forest tree breeding services. It implements a drone platform with hyperspectral and LiDAR sensors and processing to perform this task. It also assesses adaptive traits in the contrasting environment, does data processing, and develops a spruce database.
	First Resource Management Group	https://www.frmginc.com/ Provider of satellite and imagery-based forest intelligence solutions for decision -making	The First Resource Management Group is a provider of satellite and imagery-based forest intelligence solutions for decision-making.
	Chirrups	https://chirrups.app Provider of birdsong and species identification software	Chirrups is a provider of birdsong and species identification software.
QC	Nesting Safe	https://www.nestingsafe.com/ Tools provider for monitoring turtle nesting events	Nesting Safe is a tools provider for monitoring turtle nesting events. The company provides Cradal tag technology that offers a concealed radio-activated localization solution for monitoring turtle location events and environmental conditions.
	Driad AI	http://driadai.com Provider of AI- and drone-based forest inventory solutions	Driad AI is a provider of AI- and drone-based forest inventory solutions. It leverages AI and computer vision technology to analyze drone-acquired RGB and LiDAR data to offer solutions to optimize the forestry business.

[Note: AB = Alberta; BC = British Columbia; NB = New Brunswick; ON = Ontario; QC = Québec]

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