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Adapting forest management to climate change: The state of science and applications in Canada and the United States☆

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A R T I C L E I N F O

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A B S T R A C T

Over the last decade, considerable progress has been made in developing vulnerability assessment tools and in applying these methodologies to identify and implement climate change adaptation approaches for forest ecosystems and forest management organizations in Canada and the United States. However, given that adaptation processes are in early stages, evaluation of approaches across agency, organizational, and geographic boundaries is critical. Thus, we conducted a qualitative comparison of three conceptual frameworks for climate change vulnerability assessment and adaptation efforts in the Canadian and United States forestry agency contexts. We focus our comparison on components of the conceptual frameworks, development process, intended users, similarities and differences in institutional contexts (geographic and organizational), and implementation. Finally, we present case studies to illustrate how the frameworks have been implemented on the ground and in different contexts. Despite different trajectories of development, the Canadian and US forest agencies have developed similar conceptual frameworks for vulnerability assessment and adaptation. We found that key components of the conceptual frameworks included: establishing a science-management partnership; evaluating current forest conditions and management objectives; conducting detailed science-based vulnerability assessments; developing adaptation approaches and on-the-ground tactics; implementing adaptation tactics; and monitoring outcomes and adjusting as needed. However, the contexts in which these frameworks are implemented vary considerably within and between countries, mostly because of differences in land ownership, management norms, and organizational cultures. On-the-ground applications, although slow to develop, are beginning to proliferate, providing examples that can be emulated by others. A strategy for accelerating implementation of adaptation in Canada and the United States is suggested, building on successes by federal agencies and extending to public, private, and crown lands.

1. Introduction

Climate change vulnerability assessment for natural resources has been in practice in North America for approximately 10 years (Füssel and Klein, 2006; Campbell et al., 2009; Peterson et al., 2011; Johnston and Edwards, 2013; Brandt et al., 2017). *Climate change adaptation* for natural resources has been in practice in North America for about the same length of time (Blate et al., 2009; Halofsky et al., 2011b; Janowiak et al., 2011; Bierbaum et al., 2013; Littell et al., 2012; Janowiak et al., 2014; Gauthier et al., 2014; Swanston et al., 2016). This is a relatively short period of time, compared to the 30 years of scientific data available on the effects of climate change. On-the-ground *implementation of climate-informed resource planning and management* is in its early stages in most locations (Halofsky et al., 2015, 2017a; Ontl et al., 2017), and *mainstreaming of climate change*, or the

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continuous and ongoing consideration of climate change issues in forest management decision making (Williamson et al., 2012), is in its infancy (Halofsky et al., 2015).

There are several reasons why mainstreaming of climate change and adaptation implementation have not progressed more rapidly. First, resource managers and decision makers often perceive climate change as complex with uncertain effects on resource conditions (Lawler et al., 2010; Littell et al., 2012; Nelson et al., 2014), and combined with a real or perceived lack of authority to implement adaptation practices, they are hesitant to address it. Second, most resource agencies and timber management entities are already committed to existing tasks and feel that they do not have sufficient time or resources to incorporate another item into their work program (Timberlake and Schultz, 2017). Third, until recently (CCFM, 2008; Obama, 2009, 2013; USDA FS 2012), there have been no mandates or guidelines for prioritization by government agencies or other bodies (e.g., organizations that verify sustainability) to consider climate change as part of the overall mission of sustainable forest management. Finally, a lack of information at locally relevant scales required for adaptation planning and decision making might also have contributed to slow progress in adaptation (Lawler et al., 2010; Littell et al., 2012; Nagel et al., 2017). These barriers are not necessarily unique to forest management contexts; a number of adaptation scholars have identified similar issues and challenges in broader adaptation contexts (e.g., Pahl-Wostl, 2009; Moser and Ekstrom, 2010; Eisenack et al., 2014).

Despite these limitations, considerable progress has been made in assessing climate change vulnerabilities of forest ecosystems and developing adaptation options for forest management in North America (Johnston and Edwards, 2013; Janowiak et al., 2014; Le Goff and Bergeron, 2014; Halofsky et al., 2015, 2017a; Halofsky and Peterson, 2016; Swanston et al., 2017). With implementation of climate-informed planning and management starting to accelerate across Canada and the United States (US), it is an opportune time to review what has been accomplished to date, and to identify useful practices, tools, and methods of science delivery. We conducted a qualitative review of major climate change adaptation frameworks for federal and Crown forestry agencies in the US and Canada. Our objective was to compare the frameworks and implementation approaches to identify similarities and differences in key components of the frameworks and their application, identify strengths and limitations, and determine next steps for the facilitation of climate change adaptation in forest management across the northern tier of North America. The authors of this paper have observed that the conceptual basis and guidelines for climate change adaptation in Canada and the US are remarkably similar, but the manner in which implementation occurs across geographic and political landscapes differs between the countries. Thus, we provide examples of implementation of the frameworks to highlight similarities and differences among frameworks and the contexts in which they are applied.

2. Review methods

We reviewed three major climate change adaptation frameworks used by forestry agencies in Canada and the US, including the Canadian Council of Forest Ministers (CCFM) framework (described in Williamson et al. (2012) and Edwards et al. (2015)), the Climate Change Response Framework (CCRF; https://forestadaptation.org/, described in Swanston et al. (2016)), and the Adaptation Partners framework (http://adaptationpartners.org, described in Peterson et al. (2011) and Halofsky et al. (2017a,b)). We chose these frameworks because they are either government-endorsed approaches (in the case of the CCFM approach) or are the most widely used (in the case of the CCRF and Adaptation Partners frameworks in national forest units of the U.S. Forest Service). We qualitatively compared: conceptual theory; development process; key components; intended users; scope; geographic, social, and political contexts; and implementation approaches.

Section 3 provides descriptions of the adaptation frameworks. Section 4 provides case studies which were chosen by the authors to illustrate application of the frameworks in different contexts. Section 5 provides an evaluation of the frameworks, and identifies key elements, strengths and limitations, and important differences in application. We conclude with a discussion of lessons learned through implementation of the frameworks and potential next steps to further climate change adaptation in forestry.

3. Adaptation framework descriptions

3.1. The need for new approaches and conceptual frameworks

The requirement for new tools and approaches is based on recognition among forest managers in Canada and the US that climate change introduces a number of new challenges. Climate change is unprecedented; consequently, novel effects on forests can be anticipated, and innovative and untested response strategies may be required (Millar et al., 2007). Climate change is dynamic and ongoing, necessitating a forward-looking approach to forest management. The effects of climate change on forest systems and processes are complex, and there is an increased level of uncertainty about what future forests will look like, requiring adaptive management approaches (Peterson et al., 2011).

Climate change can cause multiple co-occurring changes in growing seasons, growing conditions (temperature and soil moisture), site conditions (wet, dry, melting permafrost), winter minimum temperatures and frost-free days, phenology, biotic disturbance (insects and disease), and abiotic disturbance (wildfire, extreme weather events, drought) (Fischlin et al., 2007; Edwards and Hirsch, 2012; Price et al., 2013; Peterson et al., 2014). Potential forest management-related effects include changes in forest health, regeneration success, growth and productivity, distribution and composition of species, forest structure, and age-class distribution. These effects, in turn, have implications for forest management goals, including biodiversity, ecosystem health, carbon, timber supply, non-timber goods and services, habitat, outdoor recreation, conservation, public safety, and social and cultural values (Edwards and Hirsch, 2012; Gauthier et al., 2014; Peterson et al., 2014). Thus, there is a need for a comprehensive and multi-faceted approach to climate change vulnerability assessment and adaptation.

The challenges noted above mean that new approaches to decision making and new kinds of information are required in support of forest management (Williamson et al., 2012). Assessments of current and potential future effects of climate change facilitate identification of robust and effective adaptation options and can also motivate engagement by raising awareness of possible risks. However, these assessments need to be forward looking, account for uncertain future climate, and be sufficiently comprehensive to consider multiple aspects of sustainable forest management. Given the complexity and uncertainty of effects, adaptation decision making will be most effective if it is part of a continuous process of implementation, monitoring, and modification (or adaptive management) (Millar et al., 2007; Peterson et al., 2011; Littell et al., 2012).

3.2. The Canadian approach to vulnerability assessment and adaptation

3.2.1. Institutional context

Most (94%) of the forest land in Canada is retained under public ownership (NRCan, 2016). Provincial and territorial governments manage most of this public forestland. The goals of forest management across Canada are generally consistent with principles of sustainable forest management. Sustainable forest management is defined as "management that maintains and enhances 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" (CCFM, 2008). Provincial and territorial forest management agencies have the primary responsibility for identification and implementation of measures to adapt forest management to climate change in Canada.

The forest industry in Canada obtains rights to harvest timber on crown lands through various kinds of tenure arrangements. Tenure arrangements for larger industrial developments tend to be area based and longer term (e.g., 20-year durations). Tenure arrangements require companies to fulfill certain management obligations (e.g., reforestation, forest management planning, forest pest management, harvest regulation, roads) following rules and standards established and enforced by provincial or territorial governments. Companies are also required to pay royalties and to undertake timber harvesting in a manner that minimizes effects on water, soils, recreation areas and tourism sites, visual quality of the landscape, and habitat. The forest industry is important for Canadian forestry adaptation to climate change because many of the suggested options for adaptation may require implementation by companies on crown lands. Hotte et al. (2016) note that differences in the distribution of costs and benefits of adaptation between private firms and governments need to be considered in the context of planning and implementation of forest management adaptation measures on crown forestlands under tenure to industry. At the same time, the Forest Products Association of Canada supports adaptation, and a number of individual forest companies (e.g., Millar Western (Van Damme et al., 2008)) in Canada are beginning to incorporate climate change into their long-term planning processes (also see Section 4.2).

In addition to provincial forest management agencies and the forest industry, other organizations in Canadian forestry that contribute to climate change adaptation include academic institutions (forest research), forest industry associations (communications, collaborations, government relations), forestry professional organizations (education outreach, knowledge exchange, contributions to policy development), certification bodies, and the Government of Canada. There is also a growing role of First Nations and Indigenous governments and communities in forest management, and in some cases they have been at the leading edge of considering climate change in forest management planning (Ogden and Innes, 2008).

The federal government role in forestry adaptation (delivered through Natural Resources Canada, Canadian Forest Service [CFS]) includes climate change science, communications and awareness, and leading, contributing to, coordinating, or supporting various national and international forestry-related initiatives (e.g., CCFM, national forest inventory, North American Forestry Commission). Unlike the U.S. Forest Service (USFS), the CFS does not manage forested land and works collaboratively with provincial and territorial government agencies, forestry companies, and other land management agencies to deliver science to forestry policy makers and practitioners.

3.2.2. The state of climate change adaptation in Canada

The potential effects of climate change on Canadian forestry have been a topic of research and discussion since the mid-1980s (Pollard, 1985). Recognition of the challenges to sustainable forest management posed by climate change resulted in the CCFM identifying climate change as one of two issues of national concern for Canadian forestry (CCFM, 2008). Since 2008, provincial and territorial forest management agencies have (to varying degrees) initiated a number of adaptation-related measures (Table 1).

Overall, the state of adaptation by Canadian forest management agencies can be characterized as being in the early stages. All jurisdictions are taking adaptation steps. Larger forest management jurisdictions (e.g., Alberta, British Columbia, Ontario, Quebec) have made climate change adaptation a top priority, and they are moving adaptation from information gathering and dissemination to initial implementation of new approaches that address climate change. Smaller jurisdictions lack the science capacity, funding, and complements of staff to make comparable progress on climate change adaptation but are nonetheless moving forward. In many cases, adaptation by provinces has been supported by undertaking comprehensive vulnerability assessments.

Table 1
Adaptation measures implemented by provincial and territorial forest management agencies (a), and adaptation measures being considered by forest management agencies in Canada (b).

(a) Adaptation measures implemented in Canada
Developing climate change strategies and action plans
Developing practitioner guides to adaptation
Developing climate change performance measures and a score card
Completing vulnerability assessments
Undertaking knowledge exchange, communications, and education initiatives
Developing provincially relevant climate scenarios
Reviewing, and in some cases modifying, seed transfer guidelines to facilitate assisted migration
Undertaking research into assisted migration, climate impacts assessment, and climate modeling
Supporting new science and science-policy integration initiatives
Applying techniques to reduce wildfire risk in communities near or in flammable forests
(b) Adaptation measures under consideration in Canada
Continuing to develop and enhance science and science delivery to meet requirements for new knowledge in support of climate change adaptation
Integrating adaptation and mitigation in developing climate change response strategies in forest management
Adapting wildfire management strategies to reduce risk in forest-based communities
Mitigating insect and disease risk
Developing and implementing methods for climate-based seed transfer, species selection, and stocking standards
Adapting forest industry operations
Incorporating climate change considerations into approaches for dealing with endangered species, such as woodland caribou
Assessing the implications of climate change on forest management at multiple scales

In addition to provincial governments, forest industry has begun to undertake vulnerability assessments and identify adaptation options. Most commonly, companies explore vulnerability and adaptation through long-term (i.e., 20-year) forest management plans in which the focus is on long-term strategic decision making and on operational implications of climate change. In these plans, companies consider long-term wood supply, large-scale harvesting patterns, access, and silvicultural and regeneration systems. Forest management planning has emerged as an ideal vehicle within which to undertake vulnerability assessments and adaptation planning (e.g., see Section 4.2).

At the national level, climate change-related forestry adaptation work has focused on science, assessment, developing tools to support adaptation, knowledge exchange and education, and establishing communities of practice to promote discourse and the exchange of information. A range of future adaptation options are being considered in Canadian forest management (Table 1).

There are a number of significant social factors that will affect future adaptation pathways in Canadian forest management, including the degree to which forest management systems are successful at: reducing barriers to enhanced and integrated adaptation and mitigation; identifying, negotiating, and addressing renewed relationships with Indigenous peoples; and revisiting and updating forest management norms, standards, philosophies, institutions, and assumptions to account for climate change (Klenk et al., 2011, 2014). There are potential interactions, trade-offs, and synergies in adaptation and mitigation in forest management contexts (Williamson and Nelson, 2017), and there is emerging recognition of the need for development and implementation of a coordinated approach to adaptation and mitigation in Canadian forest management. Forest managers in Canada have noted that the best mitigation strategy could be an adaptation strategy that preserves forest capital under a changing climate. There are, however, a number of barriers to an enhanced and integrated adaptation and mitigation strategy in forest management. Williamson and Nelson (2017) identify and describe these barriers and discuss possible steps to address them. Differences between agents in frameworks and beliefs about

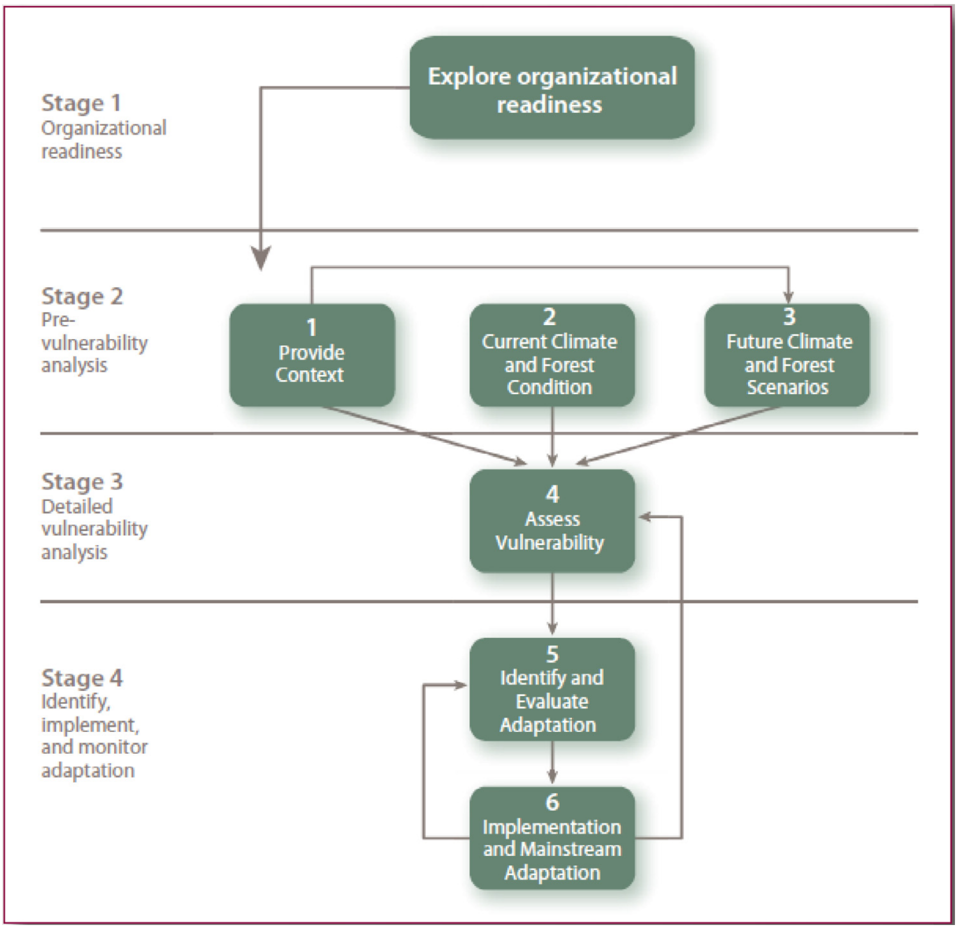

Fig. 1. Four stages of adaptation to climate change in the context of sustainable forest management. Reproduced from Williamson et al. (2012); reprinted with permission.

adaptation and mitigation within the forest management communities are a significant barrier to even initial consideration of integrated approaches. The vulnerability assessment approach is amenable to joint consideration of the effects of climate change on adaptation and mitigation objectives and could be employed to provide information in support of discourse on the merits of coordinated adaptation and mitigation strategies (Williamson and Nelson, 2017).

The majority of Indigenous communities in Canada are located in forested areas. These communities have close economic, social, and cultural ties to the surrounding forest, and they are vulnerable to climate change both because of potential effects on these communities (e.g., floods, fires, drought, impacts on cultural values, economic impacts) and also because of adaptation challenges related to economic and institutional issues. A defining feature of sustainable forest management in Canada (CCFM, 2006) is recognition of treaty rights and the need for consultation and engagement with Indigenous communities on aspects of forest management that may affect these communities. There is growing recognition of the need to engage with Indigenous communities about climate change adaptation in forest management, especially in cases where First Nations have tenure rights and/or co-management agreements. Engagement with Indigenous communities will be an important component of future discourses aimed at developing strategies for climate change adaptation in Canadian forest management and an important component of future applications of the vulnerability assessment approach.

Climate change has important implications for forest management objectives (e.g., definitions of sustainable forest management); for norms, philosophies, and assumptions that underlay forest management; and for institutions that guide forest management (e.g., policy, laws, certification standards) (Klenk et al., 2011, 2014; Steenberg et al., 2013; Williamson and Edwards, 2014; Edwards et al., 2015). It is important, therefore, that climate change considerations become incorporated into objectives, norms, standards, and institutions and that assumptions (e.g., climate stationarity) are updated to reflect the new normal. Currently, climate change considerations are not typically included in definitions of sustainable forest management, in certification standards, and in laws and regulations. This may not be critical, because there is sufficient flexibility in forest management regulatory systems to make the necessary adjustments in guidelines and practice standards to accommodate initial adaptation. However, it is expected that over time, as social and policy learning takes place, more significant transformational change to account for climate change effects will take place. Continued investment in vulnerability assessments can contribute significantly to social and policy learning processes and has a large role to play in supporting the development of adaptation and mitigation strategies.

3.2.3. The Canadian Council of Forest Ministers approach to mainstreaming adaptation

In 2008, at the request of the Canadian Premiers, the CCFM established a Climate Change Task Force (CCTF) to assess the vulnerability of tree species to climate change (Johnston et al., 2009) and to develop tools and approaches for addressing climate change (Edwards and Hirsch, 2012). The CCTF was composed of a working group of provincial and federal government (i.e., CFS) representatives and a technical analysis group to support the working group. The CCTF developed a series of publications that outlined a national framework for assessing and adapting to the effects of climate change, with a central theme of sustainable forest management for climate change vulnerability assessments and adaptation (Edwards and Hirsch, 2012; Gray, 2012; Price

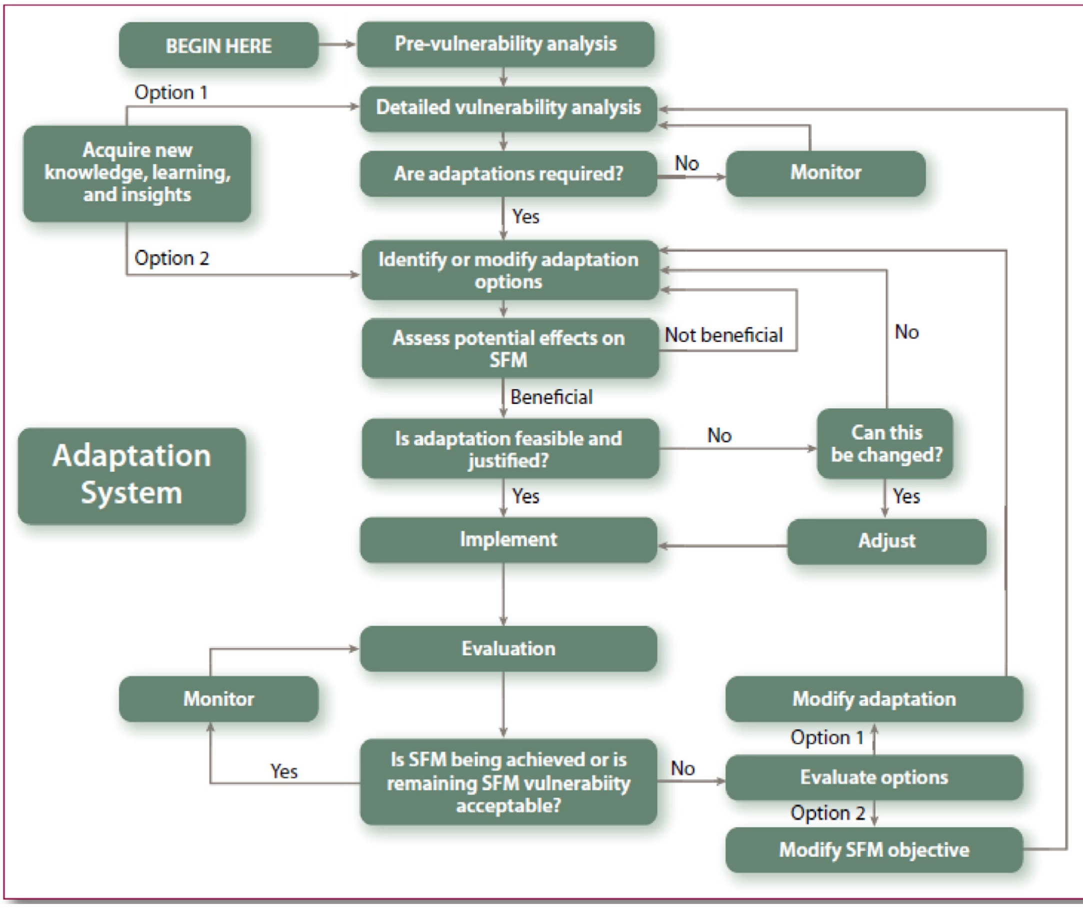

Fig. 2. Decision-analysis framework for adaptation to climate change. Reproduced from Williamson et al. (2012); reprinted with permission.

and Isaac, 2012; Williamson et al., 2012; Williamson and Isaac, 2012; Johnston and Edwards, 2013; Ste-Marie, 2014; Williamson and Edwards, 2014; Edwards et al., 2015). Although the CCFM initiative provided top-down leadership, the concepts and theories embedded in the CCTF approach were developed through lessons learned from early adopters of the vulnerability assessment approach in Canada (Johnston and Edwards, 2013).

Unlike many existing vulnerability assessment approaches that focus on ecosystems or specific species of concern (e.g., Gleeson et al., 2011; Glick et al., 2011), the CCFM approach focuses directly on forest management systems by assessing vulnerability of sustainable forest management goals and objectives. The approach recognizes the need for forest management organizations to have sufficient capacity to implement adaptation (Williamson and Isaac, 2012). The foundation of the CCFM approach is a scalable conceptual framework that provides a structured methodology for assessing vulnerability of sustainable forest management systems (Fig. 1), and a decision framework for continual development and implementation of adaptation options in response to identified vulnerabilities (mainstreaming) (Fig. 2).

In 2015, the CCFM released a step-by-step guidebook to assist forestry managers and practitioners in applying the adaptation approach developed by the CCFM to their management planning processes (Edwards et al., 2015). The guidebook provides a systematic and structured approach for organizing information to support adaptation and to mainstream adaptation into forest management decisions on a continuous basis. There are six components consistent with the framework developed by the CCFM CCTF (Williamson et al., 2012):

- Component 1 – Provide context: The first step of assessment is to describe the need for an assessment, how the results will be used, and to evaluate the capacity of the organization to undertake a comprehensive vulnerability assessment and identify whether there is a need for outside support.
- Component 2 – Describe current climate and forest condition: Describing the current relationships between climate and forest condition helps forest managers begin to understand the relationships between climate, forests and forest processes (e.g., wildfire), and forest management.
- Component 3 – Develop scenarios of future climate and forest conditions: Developing adaptation options requires some level of understanding of how climate change will affect forest conditions in the future. Price and Isaac (2012) identify how forest effects scenarios can be developed.
- Component 4 – Assess the vulnerability of sustainable forest management objectives to current and future climate: Vulnerability is a function of current and potential future effects on forest management objectives and the current adaptive capacity (see Williamson and Isaac, 2012) of the forest management system of interest.
- Component 5 – Develop and refine options for adaptation: This stage of the assessment involves a process whereby the organization undertaking an assessment works with local knowledge and subject matter experts and uses the results of the detailed vulnerability assessment (component 4) to inform, develop and refine options for adaptation.
- Component 6 – Implement and mainstream options for adaptation: Mainstreaming adaptation is a continuous process with the following elements:
  - o Potential effectiveness of suggested adaptation options is assessed
  - o Feasibility, costs, and benefits of proposed adaptations are evaluated, and recommended adaptations are identified

- o Recommended adaptations are implemented
- o Adaptation performance is evaluated
- o Adaptations or management objectives are modified
- o New knowledge is acquired on a continuous basis
- o The management system is continuously monitored to determine if unexpected effects are occurring and if management objectives are being achieved.

The guidebook, and the framework on which it is based, is sufficiently flexible to be applicable to a wide range of forest management contexts, from assessments of community-level forest management plans to national-scale assessments. There is growing recognition that sustainable forest management planning and operations need to align with broader landscape management goals, such as conservation of species at risk. The scope and scale of the assessment are user-defined based on the landscape and governance context relevant to their decision-making scope. The CCFM vulnerability assessment approach provides an opportunity for forest management agencies to partner with other land management organizations, environmental non-government organizations, and Indigenous governments and communities to develop integrated climate change adaptation approaches to landscape-level issues.

Although all forestry ministries across Canada have endorsed the CCFM approach, no national mandate exists to encourage its adoption. Each province, territory, and forestry company can choose to use the approach as they see fit (if at all). Implementation of the CCFM approach has been limited to date, although a few case studies are emerging (e.g., see Section 4.2).

The CCTF provided a series of train-the-trainer workshops during its mandate to ensure capacity to use the guidebook existed within each province and territory. The CFS provides guidance and some scientific expertise to forest managers using the guidebook to assess vulnerability in their management plans, although capacity to collaborate broadly in vulnerability and mainstreaming assessments is limited.

3.3. U.S. Forest Service and partners approach to vulnerability assessment and adaptation

The USFS manages the country's 154 national forests and 20 national grasslands, comprising 780,000 km^2 (25% of all federal lands), 87% of which is west of the Mississippi River. Forest ownership patterns vary across the country. Western national forests tend to be large blocks of contiguous land, often bordered by other public lands (other federal agencies, states) and tribal lands, as well as private lands. In contrast, most forestland in the eastern US is privately owned (74% in the northeast, 87% in the southeast; Oswalt et al., 2014). Private lands can include large tracts owned by private companies that manage for timber production, and numerous smaller tracts typically owned by families that manage across a continuum from active timber production to passive or conservation-focused management. The USFS maintains a scientific organization that conducts research and consults with the USFS National Forest System and a wide range of other stakeholders. In addition, the USFS State and Private Forestry program coordinates with state and private land owners on a wide range of issues, including fire management, insects, and disease.

A direct link to federal lands within its own agency makes it relatively straightforward for the USFS to deliver climate science and develop climate-informed programs to resource managers and planners. As a result, many on-the-ground applications of climate adaptation in forest ecosystems in the US have occurred in national forests (e.g., Nagel et al., 2017). However, the difference in land ownership between the eastern and western US has also led to some differences in real-world applications. In the midwestern and northeastern US, climate change adaptation measures have been implemented in forests managed by federal agencies, Native American tribes, states, counties, private entities, and in urban forests (Swanston et al., 2016). This application has depended heavily on a diverse array of partners that includes all three branches of the USFS (National Forest System, Research and Development, State and Private Forestry). In the western US, the research branch of the agency, in collaboration with the Office of Sustainability and Climate, has been responsible for nearly all applications.

Developing guidance for the USFS has been mostly a grass-roots effort by a consortium of federal scientists, using a similar conceptual framework (described in Peterson et al., 2011; Swanston et al., 2016; and below). However, to date, this guidance has not been designated by the agency as official direction for climate change activities. Both frameworks emphasize the scientific basis for assessing and responding to climate change, and neither is intended to prescribe specific actions in resource planning and management. More specific descriptions are provided in the following two sections.

3.3.1. Adaptation Partners framework

Climate change vulnerability assessments and development of adaptation options in the western US have been led by the Adaptation Partners team (http://adaptationpartners.org), which develops science-management partnerships among national forests, other federal and state agencies, universities, and non-governmental organizations and stakeholders. These partnerships focus on the effects of climate change on not just forest ecosystems, but non-forest vegetation, water resources, fisheries, wildlife, recreation, cultural resources, ecosystem services, and infrastructure (roads, buildings, etc.). The process used by Adaptation Partners consists of (1) development of a science-management partnership, (2) development of science-based vulnerability assessments for resource areas of interest, (3) identification of adaptation strategies and tactics in hands-on science-management workshops, and (4) implementation of adaptation options in planning and management (Halofsky and Peterson, 2016; Halofsky et al., 2017a,b). To date, Adaptation Partners has engaged 1300 resource managers and 100 research scientists to conduct assessments for 40 national forests and 32 National Park Service units, covering 27 million hectares (Halofsky et al., 2017a,b).

3.3.2. The Climate Change Response Framework

Climate change vulnerability assessments and development of adaptation options in the eastern US have been led by the Northern Institute of Applied Climate Science (NIACS; https://www.nrs.fs.fed.us/niacs). In order to address many of the challenges that land managers face when considering climate change and to accommodate the diverse land ownership base in the east, NIACS launched a community effort called the Climate Change Response Framework (CCRF; https://forestadaptation.org/) as a collaborative, cross-boundary approach among scientists, managers, and landowners. Since 2009, the CCRF has developed science-management partnerships on forestland owned and managed by private individuals; forest industry; Native American tribes; state, local, and federal agencies; and non-governmental organizations. The CCRF approach contains four components (Fig. 3a):

1. Partnerships: Climate change is a cross-boundary issue because all lands will be affected in some way. Collaborative partnerships are the foundation for all activities. CCRF activities from assessments to adaptation demonstrations include over 150 organizations.
2. Vulnerability assessment: Understanding the potential effects of climate change on ecosystems is needed to sustain healthy forests in the face of changing conditions. NIACS has published eight ecoregional assessments, and one more assessment is currently under review; these assessments cover 99 million ha and include over 150 authors from multiple organizations.
3. Adaptation resources: Information, strategies, and tools are available to help forest managers integrate climate change information into land management planning and decision making. The Adaptation Workbook (https://adaptationworkbook.org) walks

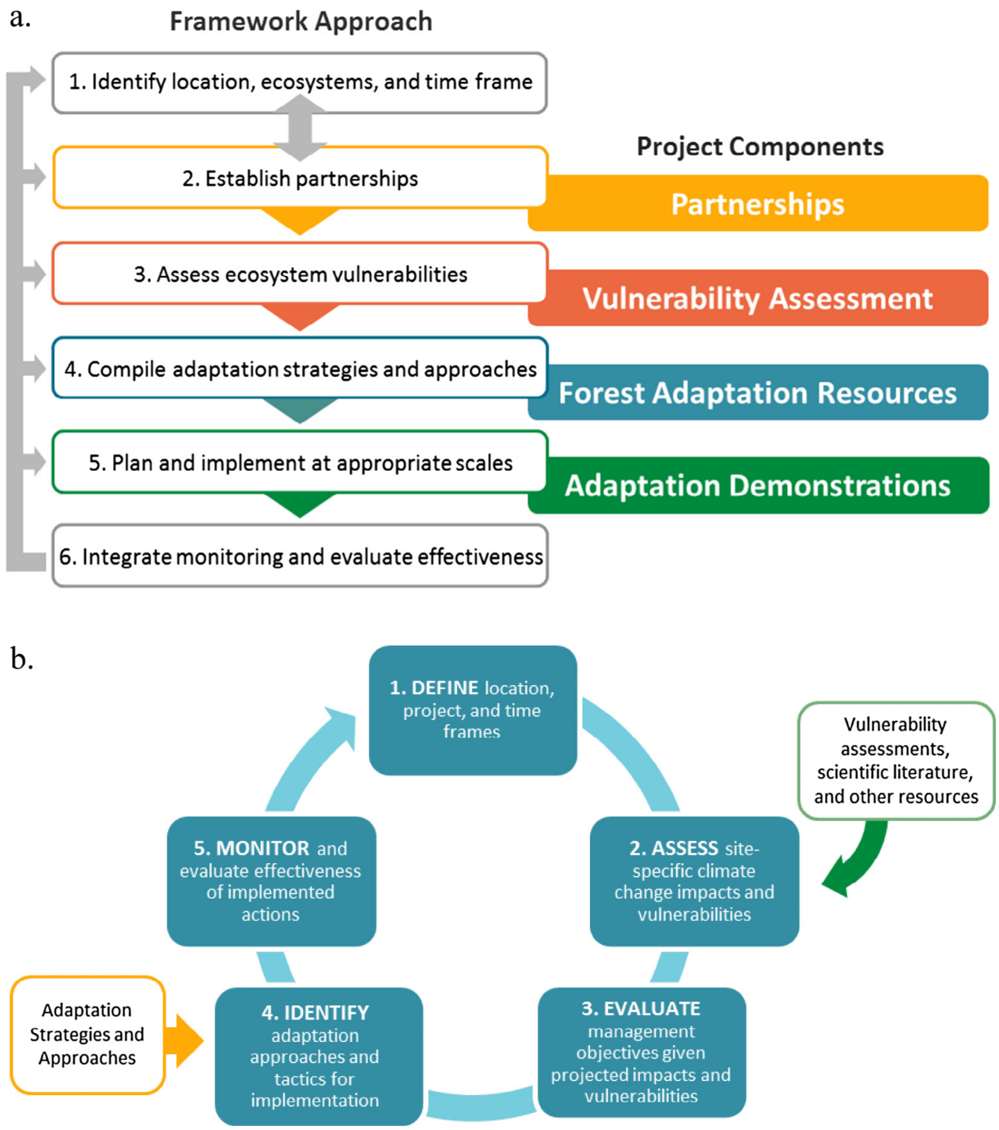

Fig. 3. (a) The US Forest Service and NIACS launched the Climate Change Response Framework (CCRF) to help incorporate climate change considerations into natural resource management in the eastern US. The approach can be adjusted and applied to varied locations and landscapes. (b) One of the key decision-making tools within the Forest Adaptation Resources is the Adaptation Workbook, which outlines a flexible process to help managers explicitly consider climate change in their resource management projects.

managers through a flexible decision-support process and integrates adaptation strategy menus with specific menus covering forests, urban forests, forested watersheds, and agriculture (Swanston et al., 2016) (Fig. 3b).

4. Adaptation demonstrations: Demonstrations provide real-world examples of climate change adaptation in forest ecosystems and test new ideas and actions. Demonstration projects are created by managers who use the Adaptation Workbook to design adaptation tactics; these tactics help managers meet their objectives and can be integrated in forest management activities. Over 200 demonstration projects have been developed throughout the midwestern and northeastern US (Swanston et al., 2016).

4. Implementation of climate-informed projects

Here we describe select examples of how climate change adaptation frameworks developed by the CCFM and USFS have been implemented on the ground. In each case, a diverse membership of participants working to ensure sustainability of forest resources in a changing climate was critical to projects moving forward.

4.1. Implementation of the Adaptation Partners framework: Forest vegetation management on federal lands (US)

The Rogue River Basin of southwest Oregon has been the focus of significant dialogue related to the effects of climate change in recent years (Myer et al., 2013; Halofsky et al., 2016). Home to many endemic plant species, the Rogue Basin has the highest vegetative diversity in the Pacific Northwest region. Dry forests and woodlands are dominated by Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), ponderosa pine (*Pinus ponderosa*), Jeffrey pine (*P. jeffreyi*), and tanoak (*Notholithocarpus densiflorus*), with multiple oak species at lower elevation and in valleys. Steep topographic gradients and a strong mediterranean climate historically drove frequent fire regimes with mixed-severity effects, and several large fires (up to 200,000 ha) in the region since 2000 have been a source of concern for long-term management, especially given that fire frequency is projected to increase in a warmer climate.

The Applegate Adaptive Management Area (131,400 ha) is located in a watershed in southwestern Oregon that is jointly owned and managed by the USFS and Bureau of Land Management. Previously developed project goals and proposed activities were reviewed by a

Table 2
Revisions to management activities for a southwest Oregon restoration project, suggested by managers after considering climate change. Adapted from Halofsky et al., 2016.

Project objectives	Project activity	Challenges to meeting goals/objectives because of climate change	Suggested revision to project activity
Restore plantations to more resilient conditions	Noncommercial thinning	Plantation stock may be poorly adapted to future climate and have low resistance to some insects and diseases	Create gaps, and reduce planting density to reduce moisture stress; plant diverse genotypes and species that may be better adapted to future conditions; when possible, use fire to reduce future fire risk
	Commercial thinning	Increased moisture stress and fire risk	Identify and target plantations that might threaten more resilient areas; use radial thinning around pines
Reduce risk to communities and other developed areas from wildland fire	Noncommercial thinning	Increased fire risk	Increase thinning activities in the wildland-urban interface
Mitigate natural stand conditions that contribute to insect and disease outbreaks	Commercial and noncommercial thinning	Increased insect and disease outbreaks, particularly in overstocked stands	Increase thinning and prescribed fire activities; target older, mid- to closed-canopy stands; target pine-oak woodlands and remove shade-tolerant species
Develop and maintain complex forest habitats for wildlife	Strategic placement of habitat development treatments	Increased fire risk and vegetation type shifts	Develop habitat where it is resistant to the effects of climate change (e.g., oak woodlands will likely be more resistant than Douglas-fir stands); create similar habitat in multiple locations across the landscape; create habitat connectivity
	Legacy tree retention	Increased fire risk with climate change, and increased risk of loss of legacy structures	Favor certain species depending on aspect (e.g., more drought-tolerant pine or oak on warmer south-facing slopes); select higher vigor trees for retention; thin around legacy trees and remove duff from around the bases of these trees
Treat nonnative plants	Increase resistance to nonnative plant invasion	Vegetation shifts and potential for disturbance to increase risk of invasion	Seed native species and use locally-sourced seed; reduce impacts of treatments on existing native species; use early detection/rapid response for nonnatives
Maintain watershed health (water quality, fish habitat, and site productivity)	Increase forest canopy cover	Increased fire risk in riparian areas with less summer precipitation and lower summer stream flows	Allow thinning in riparian areas to increase tree size and function
	Plant native vegetation	Increased summer drought stress and risk of mortality in planted vegetation	Increase diversity of shrubs and trees to provide functions (e.g., shade, water storage) that may help create climate resilience in riparian areas

group of 40 resource managers and stakeholders in a workshop, using a modified version of the Climate Project Screening Tool (Morelli et al., 2012), which was developed by the USFS. The review focused on (1) challenges posed by climate change to meeting the project objectives, (2) revisions needed in project activities to address climate change effects (e.g., spatial scale, temporal scale, design features), and (3) a comparison of revised and original approaches in terms of effectiveness and feasibility. Revisions to nine project activities were developed (Table 2), mostly related to stand density management, fuel reduction, modifying species distribution and abundance, and reduction of existing stressors (e.g., nonnative plant species) (Halofsky et al., 2016). Intended to retain functionality of existing forests and woodlands in a warmer climate, these revisions are being added to the Applegate management plan, and they will be implemented in various treatments in the field. In the future, broader participation by private landowners could expand the acceptance of climate-informed management, and applications on other federal and private lands will likely increase with integration in the broader Southwest Oregon Adaptation Partnership (http://adaptationpartners.org/swoap).

4.2. Implementation of the CCFM framework: Forest management by a private corporation on crown lands (Canada)

Mistik Management Limited is a woodlands management company located in Meadow Lake, Saskatchewan. Mistik's forest management agreement (FMA) covers 1.9 million hectares of crown land and falls under the sustainable forest management system. Mistik's FMA is situated in the southern half of the mid-boreal upland ecoregion and is dominated by white spruce (*Picea glauca*), black spruce (*P. mariana*), jack pine (*Pinus banksiana*), trembling aspen (*Populus tremuloides*), and balsam poplar (*Populus balsamifera*). Forests in the region are characterized by boreal forest disturbance regimes of fire, insects, and disease (Biringer, 2003).

Mistik conducts its forestry operations within the context of a required 20-year forest management plan (FMP). FMPs are required by Saskatchewan provincial law, and they establish goals, objectives, and strategies to guide forest management activities, describe the desired future forest conditions, and seek to address land- and resource-use issues. Mistik's 20-year FMP is currently in development, providing an opportunity to incorporate climate change in the plan. With collaboration from the provincial government (Saskatchewan Ministry of Environment, Forest Services Branch), Saskatchewan Research Council, CFS, and the initiative of a doctoral student at the University of Saskatchewan, a team was formed in April 2015 to undertake a climate change vulnerability assessment to analyze Mistik's sustainable forest management system and develop adaptation options at a strategic and operational scale. The team is using the CCFM guidebook (Edwards et al., 2015) as a framework in the process.

Through the vulnerability assessment process, Mistik has come to understand the importance of mainstreaming climate change into decision making and monitoring to ensure they remain sustainable and economically viable in the future. Mistik personnel have recognized that by investing their time and resources and actively participating in every stage of the vulnerability assessment process, they have changed their conceptual approach to addressing climate change in planning, operations, and monitoring. They have increased their understanding and capacity for relating climate effects to strategic, operational, and certification issues. Mistik already has a sustainable forest management system with a strong scientific foundation, and they have discovered that many of the tools needed to adapt to climate change are already in their toolbox. These early outcomes have increased the capacity of the company to adapt their forest management to climate change, as similarly noted in Halofsky et al. (2011a).

Mistik is now at the stage of mainstreaming adaptation options at all levels in their sustainable forest management system, including strategy, operations, and monitoring. This is being carried out through the development of a comprehensive monitoring plan that is being embedded in Mistik's existing FMP. The success and positive outcomes of this process to date have been facilitated by collaborations and partnerships and the CCFM vulnerability assessment framework, increasing the capacity for Mistik to undertake a climate change vulnerability assessment and develop adaptation options that will mainstream considerations of climate change into future management decisions.

4.3. Implementation of the Climate Change Response Framework: Forest management by a public utility (US)

Providence Water (Rhode Island, USA) actively manages 5300 ha of land surrounding reservoirs that supply drinking water for municipalities in the state. Their overall forest management goal is to maintain a mosaic of diverse forested stands that are resilient to disturbances and severe weather events that could negatively affect water quality. A climate change vulnerability assessment for New England and New York (Janowiak et al., 2017) provided broad regional trends, projections, and an assessment of climate change effects.

Resource managers at Providence Water attended a workshop that helped them use the Adaptation Workbook to develop climate-informed adaptation tactics for their property. In going through the Adaptation Workbook process, they first considered how climate change might affect their property and management objectives. Adaptation Workbook responses indicated that their chief concerns included changing precipitation patterns, with less winter snow and drier conditions later in the growing season; the potential for “northern” tree species to face increasing stress; increases in severe weather events; and a likely increase in threats from insect pests, forest diseases, invasive plants, and white-tailed deer (*Odocoileus virginanus*) herbivory. However, temperature increases of 1–3 °C by the end of the century were expected to favor trees with more southerly distributions.

Providence Water was especially concerned about challenges with hardwood regeneration, leading to interest in actions that promote transition of their forests to new conditions and species. These actions involve planting a variety of species that are expected to be better adapted to future conditions although these species may not be found in native Rhode Island forests. Specific management actions include the following objectives (Table 3):

- In oak forests with regeneration failure, guide changes in species composition by planting species expected to be better adapted to future conditions (e.g., black oak [*Quercus velutina*], loblolly pine [*Pinus taeda*], pitch pine [*P. rigida*], shortleaf pine [*P. echinata*]), and tend tree seedlings as needed.
- Plant tree seedlings likely to be adapted to future conditions in areas where herbivory can be minimized and seedlings protected, taking advantage of existing deer exclosures.
- In upland oak stands, harvest declining and poor-quality trees, then conduct enrichment planting with tree seedlings likely to be adapted to future conditions.

The group developed a monitoring plan to assess deer browse and growth and survival of tree seedlings. Two sites on land owned by Providence Water have been planted with species likely to be adapted to future conditions, and plans for more planting are under consideration.

4.4. Implementation of the CCFM framework: Forest management by local resource agencies, companies, and communities (Canada)

Two examples of how the CCFM vulnerability assessment approach (Edwards et al., 2015) has been used to advance adaptation in Canada are in British Columbia. Although these projects were initiated before the development of the CCFM approach, they used a similar framework and helped to guide the development of the CCFM approach. Both projects focused on specific regions within the Province and involved collaboration between researchers and local representatives. The first project, funded by the provincial government, used climate scenarios and tree-, stand-, and forest-scale modeling to assess potential effects and risks to meeting forest management goals in the Kamloops Timber Supply Region, a 2.4-million-ha region in the southern interior of British Columbia. The modeling, with input from local managers and practitioners, was used to develop risk assessments and recommendations for altered management practices (including silvicultural prescriptions, harvesting priorities, and strategies to meet broad landscape objectives) (Nelson et al., 2011).

The second project was funded by the federal government and focused on the San Jose watershed in the central interior of British Columbia. Stand and forest modeling, along with hydrological modeling, were used to show how the landscape would change under alternative futures and the interaction of changing forest cover and the hydrological regime. In this case, the focus was on working with local stakeholders, including local governments and resource managers. Outcomes included a greater awareness of risk across a range of values and subsequent efforts to work across jurisdictional boundaries to identify ways in which those risks could be mitigated (Nelson et al., 2012).

Both projects showed the value in using this approach to generate awareness for local governments, resource managers, and local stakeholders, but also the benefits of working collaboratively to generate shared knowledge and possible options (Nelson et al., 2011, 2012). In both cases, the broader challenges in implementing those options reflect the greater political inertia that needs to be overcome and

Table 3
Adaptation approaches and tactics developed by Providence Water using the Adaptation Workbook. For a list and descriptions of adaptation approaches, see Swanston et al. (2016).

Area/Topic	Approach	Tactics
Oak forest with regeneration failure (2 ha of a larger stand)	Guide changes in species composition at early stages of stand development. Introduce species that are expected to be adapted to future conditions.	• Plant tree species expected to be better adapted to future conditions: black oak, black locust, white oak, pin oak, persimmon, sweetgum, eastern red cedar, sassafras, and loblolly, pitch, and shortleaf pines. • Conduct follow-up measurements, tending, and treatments as needed.
Nearby oak forest with deer exclosure fence	Manage herbivory to promote regeneration of desired species. At early stages of stand development, guide changes in species composition. Protect seedlings and saplings that are adapted to future conditions. Introduce species that are expected to be adapted to future conditions.	• Plant tree species expected to be better adapted to future conditions: black oak, black locust, white oak, pin oak, persimmon, sweetgum, eastern red cedar, sassafras, and loblolly, pitch, and shortleaf pines. • Conduct follow-up measurements, tending, and treatments as needed.
15-ha upland oak stand	Favor or restore native species that are expected to be adapted to future conditions. Introduce species that are expected to be adapted to future conditions.	• Harvest declining and poor-quality trees to improve the growth of the residual stand. • Plant tree species (enrichment planting and seeding) that are expected to be better adapted to future conditions: black locust, black oak, chestnut oak, persimmon, shortleaf pine, sweetgum, Virginia pine, and white oak.

institutional challenges in working across different jurisdictional boundaries managed by various government agencies (i.e., water, agriculture and forestry).

Elsewhere, the effect of policy developments that support greater local decision making in forest management in Canada have encouraged adaptation efforts. This is why community-based adaptation to the effects of climate change on forest resources has been more common in Canada than in the United States (Furness and Nelson, 2012), especially where those forest managers do not have to work across multiple jurisdictions (as these forests are on crown lands) and have flexibility in developing practices (within British Columbia). Although these communities have more limited resources and face challenges in ensuring their operations are financially sustainable, the forests are typically managed for multiple values beyond timber with an explicit focus on sustainability over the long term; consequently, many of them have actively incorporated considerations related to climate change into planning and practices (Furness and Nelson, 2012).

5. Results: Comparison of frameworks and their application

Conceptual guidance and descriptions of processes for climate change vulnerability assessment and adaptation have been developed at national levels in North America, by federal agencies in the US, and by Federal-Provincial task forces in Canada. Frameworks and documentation developed by the CCFM and in the USFS are very similar (Table 4), and key components in the processes are consistent (Fig. 4). It is noteworthy that this similarity has evolved despite institutional differences between the countries. We are encouraged by this similarity, because it suggests that alternative conceptual approaches for assessment and adaptation are limited, providing a foundation for both consistency and collaboration.

Despite differences in the origin of these programs, both the CCFM and the USFS assumed national leadership roles in (1) communication about climate change through websites, workshops, and other means, (2) development of collaborations with specific land management organizations, (3) assessment of climate change vulnerability, and (4) implementation of climate change adaptation tactics. However, the institutional context for addressing climate change in forest ecosystems varies considerably, mostly because of differences in land ownership, management norms, and organizational cultures. These institutional factors are often the key to implementation of new concepts, regardless of the quality of the scientific foundation and relevance of issues (climate change in this case), because implementation rests on the ability of others, such as policy makers, practitioners, land owners, and lease holders, to use this information and to undertake adaptation actions.

In both countries, assessment processes have led to several consistent outcomes. First, the organizational capacity to address climate change is being developed iteratively across large landscapes. This includes resource managers developing expertise on the effects of climate change and adaptation, but it also includes awareness of how climate change affects projects and plans. Second, data and information compiled during the course of assessments provide both the foundation for climate change inferences and sources for other applications (vegetation management, watershed management, etc.). Third, project publications and websites contribute to the identity of each assessment, creating a sense of ownership and pride (at least in the short term). Fourth, long-term partnerships frequently emerge, going well beyond the duration of the assessment process, often leading to follow-up projects that improve upon and extend the assessment geographically and topically (Johnston and Edwards, 2013). For example, several follow-up projects with a focus on forest management and infrastructure have occurred since release of the North Cascadia Adaptation Partnership report in Washington State (Raymond et al., 2014).

The CCFM has developed and supported the Forest Adaptation Community of Practice (https://www.ccadaptation.ca/en/facop), which is embedded within a broader, multi-sectoral Climate Change

Table 4
Comparison of conceptual frameworks for vulnerability assessment and adaptation developed in forest agencies in Canada and the US.

Conceptual framework	Conceptual theory	Development process	Implementation method	Intended users	Geographic scope
Adaptation Partners framework	Vulnerability and adaptation definition from Parry et al. (2007)	Bottom-up effort by national forests and USFS scientists	Development of a science-management partnership	National forests, other natural resource management agencies and organizations	Sub-regional to regional, primarily on federal land
Canadian Council of Forest Ministers framework	Vulnerability and adaptation definition from Parry et al. (2007)	Mandated by Canadian governments	Development of a science-management partnership	Forest resource practitioners, land managers	Sub-regional to regional, on crown and private land
Climate Change Response Framework	Vulnerability and adaptation definition from Parry et al. (2007)	Bottom-up effort by national forests and USFS scientists	Development of a science-management partnership	National forests, private land owners/managers, other natural resource management agencies and organizations	Sub-regional to regional, on federal, state, and private land

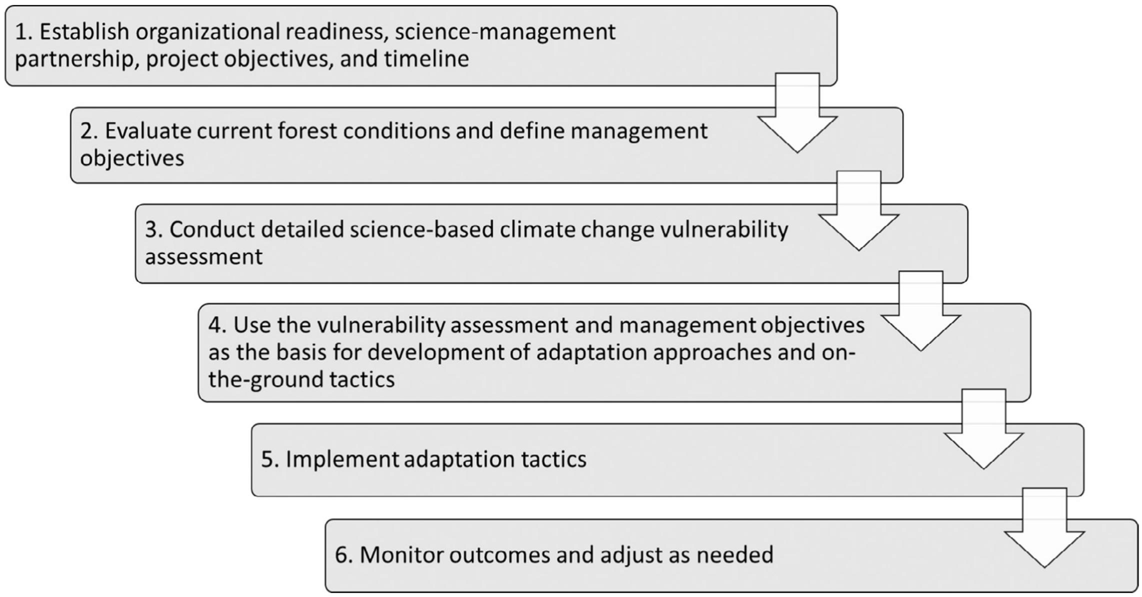

Fig. 4. Key similarities in the vulnerability assessment and adaptation frameworks developed by the Canadian Council of Forest Ministers and in the US Forest Service.

Adaptation Community of Practice (https://www.ccadaptation.ca). Both communities of practice are interactive online communities dedicated to advancing knowledge and action in climate change adaptation. They provide an opportunity for scientists, practitioners, and policy makers to ask questions, generate ideas, share knowledge, and communicate with others. These communities of practice allow the CFS and provincial/territorial forest agencies and industry to disseminate new information and guidance through a national forum, facilitating both rapid communication and consistency of practice. Consistency is also encouraged by the CFS Forest Change Adaptation Tools archive (http://www.nrcan.gc.ca/forests/climate-change/tools-resources/17770) and Forest Adaptation Database (http://cfs.nrcan.gc.ca/adaptation-options; based on Ogden and Innes, 2007; Joyce et al., 2009; and Gauthier et al., 2014), provided for forest practitioners throughout the country.

The USFS has no formal or national communities of practice for climate change, with the exception of an internal network of regional and national forest-level climate change coordinators. Communication and shared learning typically occur through this internal agency network, as well as through partnerships developed for climate change assessments and through other informal networks and projects that emerge from those assessments. This creates the possibility of inconsistency, although consistency is retained to a great extent by shared learning from one partnership to the next as they are instituted across the geographic and organizational landscape. Consistency is also encouraged by the Climate Change Adaptation Library (eight resource areas, western US; http://adaptationpartners.org/library.php) and Forest Adaptation Resources (forest, urban forest, and water resources, eastern US; https://www.forestadaptation.org/far), which provide menus of strategic and on-the-ground adaptation options. As these resources continue to grow, they are increasingly used by forest practitioners (within and outside of the USFS) as a direct source of adaptation options, as well as a point of departure for developing new options. Both the Adaptation Library and Forest Adaptation Resources are provided to USFS silviculturists through the National Advanced Silviculture Program, a program that certifies all USFS silviculturists.

In applying the conceptual frameworks described here over the past decade, we have identified several factors that lead to successful implementation of climate change assessment and adaptation projects. First, good personal relationships and clear communication are needed to develop the trust required for effective projects that may last over 2 years and partnerships that may extend beyond that (Halofsky et al., 2014). Second, the organization that is the recipient of the assessment must have early engagement of both leadership and resource managers to ensure ownership of the process and final products. Third, the more that research scientists can be embedded within the process, in direct communication with resource specialists, the better the final product will be, representing the objectives stated at the onset of the project. Finally, the best outcomes are achieved through iterative shared learning from start to finish. This can be accomplished through workshops, conference calls, and webinars, but face-to-face communication is usually the best approach for shared learning (Halofsky et al., 2014).

In the US, climate change assessments and adaptation strategies are being developed in many locations, with considerable progress in the western and northeastern parts of the country. Different land ownership patterns in the eastern and western portions of the country have led to variations in stakeholder engagement and the process for developing adaptation options. In Canada, assessments are also increasing, but slowly and without a specific geographic focus. Currently, one of the limitations is that there are as yet no dedicated resources within the various provincial agencies or territorial governments to provide ongoing support for such assessments; instead, assessments are done on an ad hoc basis, dependent in part on where interest may coincide with other supportive factors, such as external funding or pre-existing research connections. Despite the considerable effort put into such assessments, implementation or uptake may languish without sustained support from either government or local actors.

Development of climate change vulnerability assessments and adaptation strategies is not the end goal. Their ultimate value is realized only if they are translated into operational aspects of management and planning and mainstreamed into forest management decision making. This process is in its early stages in both Canada and the US, often occurring independently of the broader assessment process, motivated by specific activities such as revision of a land management plan or implementation of a forest vegetation management project. As described below, recent examples of mainstreaming through on-the-ground implementation are providing a pathway for integrating "climate change thinking" in core activities of agencies and stakeholders.

6. Discussion and future directions

Through a qualitative review, we have documented that Canada and the US have a coherent approach to assessing and responding to the effects of climate change in forest ecosystems (Fig. 4). Despite different trajectories of development, the Canadian forest agencies and USFS have developed similar guidance and processes for conducting vulnerability assessments and identifying adaptation options. Although slow to develop, on-the-ground applications are beginning to proliferate, providing examples that can be emulated by others.

Multiple projects in both countries have established that vulnerability assessments play a significant role in supporting the process of climate change adaptation. The results of these assessments provide important information about how climate change is affecting and will affect forest resources and forest management objectives. Researchers are learning more about how to undertake vulnerability assessments and engage with local forest managers in completing assessments (Johnston and Edwards, 2013; Halofsky et al., 2014, 2016; Swanston et al., 2016). It is anticipated that the methodologies, supporting data and models, and approaches for deploying them will improve over time as they are applied with increasing frequency.

Climate change assessments are now being applied in a number of different ways. First and foremost, they are being used to inform local forest managers and improve forest management projects and plans, as described above. We expect this to accelerate as land managers become more comfortable with the process and as younger employees (with more education in climate change issues) are hired in management positions. Assessments are being used in writing overarching planning documents that guide land management across large administrative areas (e.g., a national forest or a forest management unit). They are being used in risk assessments required for evaluation of proposed projects and development of alternative actions (environmental assessment). Assessments are being incorporated in restoration planning and management, based on projected resource conditions. Finally, they are being used to inform resource monitoring programs, in some cases including indicators of specific parameters that may be sensitive to a warmer climate.

Over a decade ago, when first developing programs in applied climate change science, we thought that providing scientific information and deploying a few successful projects would be sufficient—we anticipated that managers of public and private forest lands would simply use that information (or compile their own), then emulate the process. We soon learned that we were mistaken, and that each assessment requires a framework, convening of stakeholders, a unique science-management partnership (Littell et al., 2012) focused on specific landscapes and organizations, and champions to facilitate the process (Johnston and Edwards, 2013). In implementing a number of different climate change assessment and adaptation projects across Canada and the US, we have found that the keys to a successful assessment include the following tasks:

- Engage stakeholders and leadership to develop commitment, trust, and ownership (Halofsky et al., 2011b).
- Communicate well and often (face-to-face dialogue is critical), to reinforce objectives and promote shared learning (Halofsky et al., 2011b, 2014).
- Identify a realistic schedule and set of objectives, based on the amount of funding, people, and time available (Johnston and Edwards, 2013; Halofsky et al., 2014; Swanston et al., 2016).
- Work with partners outside of the lead organization to ensure diverse perspectives and build acceptance among stakeholders and local communities (Johnston and Edwards, 2013; Halofsky et al., 2014).
- Focus on sustainable resource management as the end goal, acknowledging the many climate-smart activities that are already in practice (Peterson et al., 2011).

Currently, the exchange of information and knowledge between Canada and the US about the results of climate change assessments and about lessons learned in developing and applying assessment methods occurs in an ad-hoc manner. A systematic approach to monitoring and sharing knowledge about assessment and adaptation activities in the US and Canada would encourage stronger collaboration between US and Canadian forest agencies at the research and operational level and, perhaps more formally, at the institutional level. This could occur, for example, through a memorandum of understanding on research about forestry adaptation and knowledge exchange between the USFS and CFS, collaborations through the North American Forestry Commission, or through the North American Forest Health Summit.

Sharing of knowledge and increased collaboration and coordination between the two countries on assessment methods, trials, and results has a number of potential benefits. It would provide a basis for continuous learning about, and improvement of, assessment techniques and approaches. It could provide valuable insights into how forest management practitioners use information to support adaptation decision making. It would provide a basis for monitoring adaptation progress in Canada and the US. It could also provide intelligence at a continental scale about the effects of climate change on forest management systems. Effects observed at different locations may provide early warning indicators of possible effects at other locations, and sharing information could reduce unanticipated surprises. Finally, it could show how best to support ongoing adaptation efforts, especially around increasing adaptive capacity of organizations and actors within the resource management system.

Despite recent successes, sustaining current efforts by federal, provincial, territorial, and state agencies and industry to develop climate change assessments across all forest lands will be a significant challenge in Canada and the US. Resource constraints and changing short-term priorities within the forest sector will present potential barriers to advancing assessments across the many forest management contexts that exist within the two countries. However, we are optimistic that climate change awareness, climate-informed management and planning, and implementation of adaptation in forest ecosystems will continue to evolve in Canada and the US. Sharing lessons learned among projects and discovering and using efficiencies to improve and increase adaptation implementation efforts will be critical. Within the next decade, we anticipate the following events and adjustments:

- Climate change will become an integral component of most aspects of sustainable forest management.
- Organizational capacity to manage for climate change will increase within federal agencies and local stakeholders.
- The effects of climate change on forest resources and associated human systems will be continually assessed.
- Agency planning processes will provide opportunities to manage across boundaries.
- Resource managers will implement climate-informed practices in long-term planning and management.
- There will be dedicated resources within the various forest management systems (expertise and funding) to help communicate and transfer scientific knowledge and support to managers in their ongoing adaptation efforts.

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