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Tracking forest changes: Canadian Forest Service indicators of climate change

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Abstract The article describes the development of the web-based Canadian Forest Service climate change indicator system, referred to as the Forest Change Tracking System. This indicator system was established in 2011 with financial support from the Adaptation theme of the Government of Canada Clean Air Agenda. The objectives of the Forest Change Tracking System are to (a) raise awareness and inform on the occurrence and scope of ongoing changes across Canadian forests associated with climate change and to (b) support the inclusion of adaptation into forest management planning and forest-related policies. The development strategy was to focus on a limited number of most relevant indicators and to build on existing capacity in order to produce information on current and future climate change impacts across Canada's vast forests. An initial list of 141 potential indicators relevant to forestry was compiled through a series of workshops with more than 100 researchers and forest sector stakeholders and through a global scan of climate change indicator initiatives. A rating system based on each indicator's potential relevance, sensitivity, and feasibility of measurement was used to select a subset of 35 indicators. These indicators fall within three broad systems—climate, forest, and

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human. Each indicator web page contains information on the relevance of the indicator, graphs, or maps on past trends and future projections across Canada and related links and references. This paper also presents lessons learned, discusses challenges and opportunities, and reviews potential next steps related to the broadening of this indicator system.

1 Introduction

Canadian forests cover 347 million ha which corresponds to approximately 35% of the country's land area and 9% of the world's forest cover (NRCan 2017). They are home to more than 200 indigenous and forest communities, support 200,000 jobs in all Canadian provinces and territories, and produce environmental benefits including the storage of large quantities of carbon in their soil and vegetation (Kurz et al. 2013). With climate change, Canada's temperature has already increased by 1.7 °C between 1948 and 2016 (Environment Canada 2017) and precipitation regimes have changed regionally (Zhang et al. 2011). By the end of the twenty-first century, a global increase of 2 °C could translate into a change of up to 4 °C for Canada (IPCC 2013). Canada's forests are on the leading edge of climate change impacts (Price et al. 2013), with significant past and anticipated effects in ecological processes and natural disturbance regimes (e.g., Flannigan et al. 2009; Sturrock et al. 2011; van Mantgem et al. 2009) and potentially undesirable consequences for its forest sector (Gauthier et al. 2014a; Johnston et al. 2009; Lemmen et al. 2014; Williamson et al. 2009).

Adaptation to climate change requires informed decision-making and creates an increasing demand for knowledge, information, products, and services. In 2011, Natural Resources Canada's Canadian Forest Service (CFS), the leading federal research organization on forest-related issues, initiated the Forest Change program (Anonymous 2012b, c; Ste-Marie et al. 2015) with financial support from the Adaptation theme of the Government of Canada Clean Air Agenda. The CFS collaborates on climate change adaptation with Canada's provinces and territories whose constitutional responsibilities include the management of Crown lands covering 90% of the Canada's forests. Of the remaining forest lands, 6% is privately owned among more than 450,000 landowners (NRCan 2017).

Forest Change provides information that increases the capacity of actors within Canada's forest sector to develop and implement adaptation measures to mitigate the impacts of climate change or take advantage of its opportunities. In many countries and for different sectors, this challenge has led to the development of indicators to track and communicate the complex impacts of climate change on environment and society (e.g., the U.S. National Climate Indicators System, Kenney et al. 2016; U.S. Environmental Protection Agency 2014; the UK Modelling Natural Resource Responses to Climate Change (MONARCH); and the Australian Department of the Environment). These indicators are usually set within broader climate change impacts reporting frameworks, but such a framework was non-existent for Canada in 2011 (Gauthier et al. 2014b).

Building on existing capacity, a climate change indicator system, hereafter referred to as the Forest Change Tracking System, was therefore established in 2011 by the CFS with the twin objectives (a) to raise awareness and inform about the occurrence and scope of ongoing changes across Canadian forests associated with climate change and (b) to support the inclusion of adaptation into forest management planning and forest-related policies. It reports on climate change indicators by describing past trends and future projections in Canada's forests and forest sector. The objective of this paper is to describe the development of the CFS

Forest Change Tracking System and more specifically to define the process used in indicator selection and development, to present lessons learned, challenges, and opportunities, and to outline the next steps.

2 Developing the Forest Change Tracking System: a five-step approach

Environmental indicators designed to support sustainable forest management (SFM) as related to ecological integrity (CCFM 2006) have been in use for two decades in Canada (e.g., Hickey and Innes 2008) but with no explicit consideration of the changing climate. To this day, they provide an indication of progress in meeting particular sustainability criteria such as the maintenance of biodiversity and are used to assess whether specific SFM targets have been achieved within forest management areas. By contrast, forest-based climate change indicators were non-existent in Canada prior to this initiative. This new set of indicators complement SFM indicators by capturing the effects of climate change on the forest environment and the forest sector. The incentive for tracking climate change indicators is to facilitate adaptation by the forest sector. The performance of adaptation options can then be assessed against SFM indicators.

The development of the Forest Change Tracking System was overseen by a Tracking System Team (TST) (see Online Resource 1: expert groups set up to build on indicators for the Forest Change Tracking System) and supported by an Indicators Working Group (IWG) and a Lead Experts Group (LEG). The role of the IWG was to identify and select indicators; the LEG was responsible for delivering analyses, modeling, and mapping for Tracking System indicators. Authors of this text are members of the TST.

2.1 Step 1. Envisioning the Forest Change Tracking System and its indicators

At the inception of the Forest Change program, in 2011, the TST brought together 12 CFS scientists and managers (see Online Resource 1: expert groups set up to build on indicators for the Forest Change Tracking System) from across the country to recommend key properties of the envisioned Tracking System and to assess the potential contributions of existing CFS monitoring systems. Their recommendations were as follows:

(1) Tracked information must be dynamic and updatable. Static information may be included if it supports model application or classification of impacts.
(2) Tracked information must be spatially explicit but does not need to be spatially continuous.
(3) Tracked information must be extensive in area. Ideally, indicators should be national in scope and regionally relevant and applicable.
(4) Tracked information must be accessible to the end user to account for the highly distributed and public nature of the adaptation process.
(5) The Tracking System must be scientifically defensible.
(6) Indicators should build on existing monitoring systems to report on trends in historical time series.

According to these recommendations, the IWG defined indicators for the Forest Change Tracking System as variables that are sensitive either directly or indirectly to changes in climate and that are relevant to the forest sector (Gauthier et al. 2014b). Inasmuch as possible, indicators were to be national in their coverage and based on long-term records to discern trends due to climate change from those linked to natural climatic variability. In the absence of such records, given the paucity of historical data and the regional coverage of Canadian inventories, indicators of regional relevance were accepted, as long as the influence of climate was clear and direct. Although some of the trends could not always be firmly attributed to climate change, indicators had to exhibit a strong relationship with climate. Indicators could also be estimated using proxies, that is, substitutes for direct measurements.

Although initially envisioned as reporting exclusively on past trends due to climate change, the system evolved to include future projections of changes, along with links to resources to support adaptation. Presenting forward-looking indicators (e.g., Fig. 1) alongside tracking data was seen to be the most useful synthesis of current knowledge, provided that the distinction between historical data and projections was clearly made.

2.2 Step 2. Identifying Forest Change Tracking System indicators

The initial list of potential indicators was compiled by the IWG through a series of workshops (between November 2011 and March 2012) involving more than 100 participants (see Gauthier et al. 2014b for a complete description). The first phase of consultation consisted of workshops held at each of the five CFS regional centers (http://www.nrcan.gc.

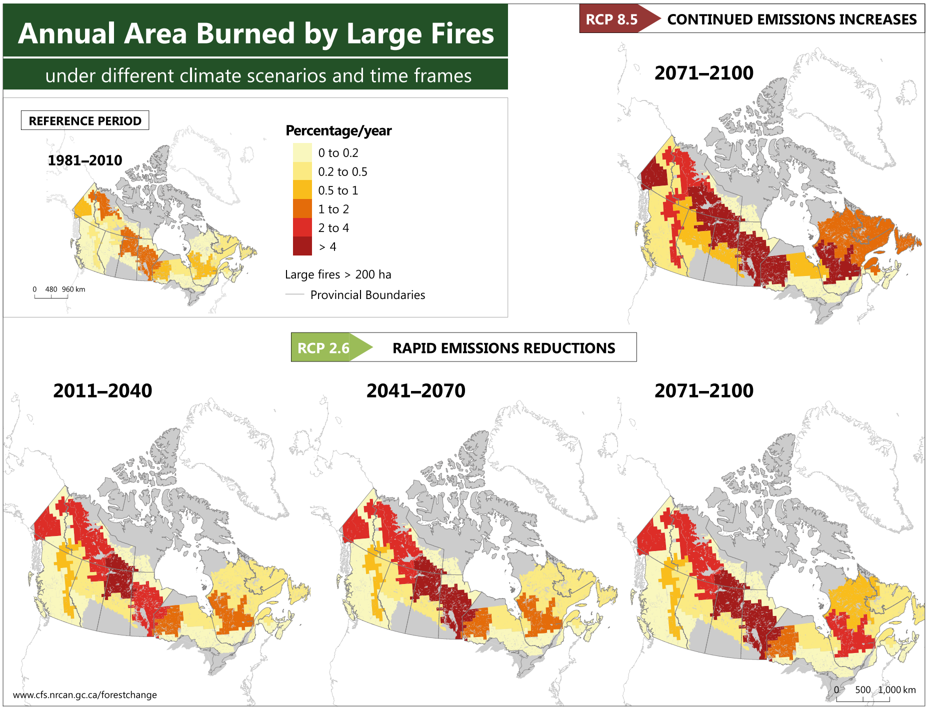

Fig. 1 Reference period (1981–2010) and projected annual area burned for the short (2011–2040), medium (2041–2070), and long term (2071–2100) under the Representative Concentration Pathways (RCP) 2.6 (rapid emissions reductions) and, for the long term (2071–2100), under RCP 8.5 (continued emissions increases). Map units represent the homogeneous fire regime zones in Canada (Boulanger et al. 2013)

ca/forests/research-centres/13445) to fully involve the CFS research community. The IWG sent background information on the Forest Change Tracking System purpose and scope and on desired indicator properties before the workshop and asked participants to propose indicators (see templates in Online Resources 2: templates used to identify Forest Change Tracking System indicators). During the three-hour workshops, participants discussed the proposed indicators and identified additional new indicators during brainstorming sessions. The participants were also asked to provide a numerical rating of their potential relevance, sensitivity, and feasibility of measurement, as defined by the six key properties identified during the initial Tracking System expert workshop (Table 1).

The second phase of the consultation process consisted of a workshop that brought together 34 forest industry, university, and provincial government representatives and climate change researchers. The objective of this workshop was to discuss the types of indicators that were needed and the potential contributions of the broader forestry community to their tracking (Anonymous 2012a; Gauthier et al. 2014b).

These consultations were then complemented by a comprehensive literature review and website scan of indicators used or in development to track climate change effects on forests and the forest sector in other jurisdictions worldwide (more than 700 documents and websites; Kremsater 2012). Particular attention was paid to existing or proposed monitoring and reporting frameworks in different provinces, states, and countries, including criteria for ranking and prioritizing indicators.

Through these workshops and literature review, the IGW compiled 141 potential climate change indicators and grouped them within three broad systems (climate, forest, and human) that form a chain of causality from the anthropogenic greenhouse gas emissions to the effects on forests and society. Indicators for the climate system are derived from climate data. Indicators for the forest system focus on forest structural attributes and functional processes which are likely to be affected by climate change. Indicators for the human system focus on the societal or economic consequences of impacts either directly from climate change or mediated through forest–climate change interactions. The IWG then developed scientific rationales to explain the linkages between climate and the forest or forest sector for all potential indicators. Finally, the IWG developed criteria to be used in the final selection and prioritization of indicators to include in the Tracking System. An information report was published to share the results of these activities (Gauthier et al. 2014b).

Table 1 Criteria used by the tracking system team to select forest change tracking system indicators

Criteria	Definition
Potential value in raising awareness of ongoing changes	The indicator is pertinent either because it provides evidence of an important change in the forest, the forest sector, or forest communities or it provides evidence of a change whose consequence for the forest or the forest sector are not yet apparent (e.g., phenology of birds)
Sensitivity to changes in climate	The indicator should be sensitive to climate and should be more so than to other drivers of change
Probability of success, which incorporates both feasibility and measurability criteria	The indicator should be measurable both empirically and objectively. Feasibility refers to the ease and workability with which measurements can be gathered, reported, and effectively used. Data collection at the appropriate sampling intensity should be cost-efficient

The initial 141 potential indicators can all provide useful information relative to climate change impacts on forests and the forest sector as they document fundamental changes hypothesized under a changing climate. Many will have to be set aside because they are too difficult to measure. However, technological advances may eventually allow the development of some that are currently too difficult to track. The indicators composition of our Tracking System may also evolve in response to changing needs and evolving knowledge.

2.3 Step 3. Selecting Forest Change Tracking System indicators

The TST used the ratings of each of the 141 indicator as provided by experts in the earlier workshops to select a subset of 35 indicators grouped by system (climate, forest, and human) and by issues to be tracked (e.g., drought, tree mortality; referred to as topics; Table 2). The process was designed to be as neutral as possible but may have had a built-in bias against socioeconomic indicators because of the low representation of these disciplines in the CFS research community. Such a bias was taken into account by the TST in the indicator selection process.

Our intent was to make the creation of indicators a living process in order to capture new needs, insights, or capacities. After the initial consultation workshops, indicator proposals were therefore invited through a yearly submission process. Proposed indicators were then evaluated by the TST and by a group of CFS experts following the same criteria, and, if pertinent, were incorporated to the Tracking System.

2.4 Step 4. Incorporating indicators into the Forest Change Tracking System

For each of the top-ranked indicators for which the CFS had existing expertise, capacity, and data, the TST identified a lead expert to provide analyses, modeling, and mapping and thus constituted the Lead Experts Group (LEG) (Online Resources 1: expert groups set up to build on indicators for the Forest Change Tracking System).

During the design and implementation of the web-based Forest Change Tracking System, the TST worked with the LEG to develop and apply standards for text format and content, as well as for graphs, maps, references, and related links (www.cfs.nrcan.gc.ca/forestchange). Each indicator page had to contain sections describing why the indicator is important, what has changed, and what the outlook is, along with supporting graphs, maps, and related links and references. The current or baseline information would refer to the period 1981–2010 while projections were to be done for three timelines: short (2011–2041), medium (2041–2070), and long term (2071–2100). Also, all projections of indicators were to be made using the Representative Concentration Pathways (RCP) 2.6, 4.5, and 8.5 of the 5th Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC).

Scientific credibility was ensured by only incorporating into its Tracking System website data that had already been published in peer-reviewed papers or in other government or academic reports. Website structures of other monitoring programs (e.g., the European Environment Agency, United States Environmental Protection Agency, U.S. Global Change Research Program) inspired the development of the Forest Change Tracking System content format.

Table 2 Forest change tracking system indicators including fully documented (in bold), under development (regular font) and indicators for which development capacity is currently limited currently (italics)

System	Topic	Indicator	Data sources	Spatiotemporal information
Climate	Drought	1. **Climate Moisture Index (CMI)** 2. **Palmer Drought Severity Index (PDSI)** 3. **Soil moisture index (SMI)**	- Long-term climate normals - Climate Impacts on Productivity and Health of Aspen (CIPHA)	- Past trends (1890–2010) - Projections - National, closer look into the Prairies
	Fire weather	4. **Start of fire season** 5. **End of fire season** 6. **Length of fire season**	- Canadian Wildland Fire Information System (CWFIS)	- Projections - National
	Extreme weather events	7. Windthrow	- Environment and climate change weather stations - North American Regional Reanalysis (NARR)	- Past trends (1961–2010) - Projections - Regional coverage (eastern Canada)
		8. *Lightning*	- Canada Lightning Detection Network	
		9. *Thunderstorms*	- Environment and climate change weather stations	
	Length of growing season	10. Standard and nonstandard degree days	- Environment and climate change climate stations	- Past trends (1901–2100) - Projections - National coverage
	Permafrost	11. Permafrost temperature	- Canadian Permafrost, Geological Survey of Canada	- Past trends (1980–2015) - Regional coverage (eastern Canada)
Forest	Fire regime	12. **Annual area burned** 13. **Number of large (> 200 ha) fires** 14. **Fire seasonality**	- CWFIS	- Past trends (1959–2010) - Projections - National coverage - Projections - National coverage
	Pest incidence	15. Pest species distribution	- National Forest Pest Strategy Information System (NFPS-IS) - National Forestry Database (NFD) - Forest Insect and Disease Survey (FIDS)	- Past trends (1900–2010) - Projections of climatic suitability - National coverage - Closer look into affected regions (mountain pine beetle, spruce budworm, forest caterpillar, and gypsy moth)
	Pathogen incidence	16. Incidence of forest pathogens	- Canadian Food Inspection Agency (CFIA) - Pest Management Regulatory Agency (PMRA)	- Past trends
	Tree mortality	17. **Percent annual loss of living tree biomass**	- CIPHA	- Past trends (1950–2002) - Regional coverage (Prairies)
	Forest growth	18. Change in biomass and wood volume 19. Annual growth rings 20. Net primary productivity	- Canada's National Forest Inventory (NFI) - CIPHA	- Past trends (from 1971 to 2010) - Projections (6 species) - National coverage
	Tree regeneration	21. *Success and failure of natural forest regeneration postharvest and post disturbance* 22. *Success and failure of assisted migration blocks*	- Provincial governments records - Individual companies' data	

Table 2 (continued)

System	Topic	Indicator	Data sources	Spatiotemporal information
		23. *Tree cone and seed crop production*		
	Phenology	24. *Timing of bud burst*	- Volunteer networks (e.g., PlantWatch) - Weather Network Pollen Forecasts - Webcams at Fluxnet sites and national parks - Provincial seed orchard records, maple syrup producers, etc.	
	Tree species distribution	25. **Distribution of tree species**	- Plant hardiness zones for past trends - Projected climate suitability zones for future projections	- Index for past trends (1931–1990) - Projections of climate envelopes - National coverage - Available for 112 forest species
	Biodiversity	26. *Habitat to support diversity* 27. *Shrubs diversity* 28. *Bird diversity* 29. *Genetic diversity*	- Bird Conservation Regions (BCR)	
Human	Cost of fire protection	30. **Wildland fire suppression expenditures**	- Provincial and territorial government agencies and Parks Canada, for Canada's national park lands - Canadian Interagency Forest Fire Centre (CIFFC)	- Past trends (1970–2005) - Projections - National coverage
	Wildland fire evacuations	31. **Annual number of evacuations** 32. **Annual number of evacuees** 33. **Location of evacuation**	- Web searches and articles - CIFFC - Government agencies and supporting organizations	- Past trends (1980–2015) - National coverage
	Wildland Urban Interface	34. Population at risk of forest fire	- Statistics Canada - Aboriginal Peoples Survey database - Canada's Forest Ecumene	- Past trends - National coverage
	Forest access	35. *Freeze–thaw of winter roads*	- Environment and Climate Change climate stations	

Topics and indicators in bold are fully documented under the first funding phase (2011–2016) and can be accessed through our website (www.cfs.nrcan.gc.ca/forestchange). Indicators in regular font are under development; they require additional work (analyses and editing) to be completed under the second funding-phase (2016–2021). For indicators in italics, the CFS has limited capacity. Projections were modeled using the Representative Concentration Pathways (RCP) 2.6, 4.5, and 8.5 of the 5th Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) for three timelines: short (2011–2041), medium (2041–2070), and long term (2071–2100). Baseline information refers to the period 1981–2010

2.5 Knowledge exchange and website publication

Starting in April 2014, a beta-version of the Forest Change website was circulated among 125 potential end users along with a survey to get feedback on the indicators' texts, graphs, maps, references, and general structure. To optimize the web applicability in adaptation decision-making, interactions were sought with end users, including forest industry, university, government representatives, and climate change researchers and policy staff through workshops, webinars, and presentations. The system was put online in January 2016.

The Government of Canada's website content is meant for a general audience and scientific information has therefore to be summarized into clear and accessible language. Forest Change website content is organized in standardized sections containing the information synthesized and formatted to comply with Government of Canada guidelines related to format and accessibility. Embedded hyperlinks enable specialized users to access more detailed information.

3 The current Forest Change Tracking System

3.1 Published indicators

Between 2011 and 2016, an initial set of indicators (Table 2) was fully documented and can now be accessed through the Forest Change website (www.cfs.nrcan.gc.ca/forestchange). Monitoring Canada's forests and how they change is challenging given their extent and remoteness. Satellite-derived monitoring (Beaudoin et al. 2014; Guindon et al. 2014) was very useful for interpolating observations for several indicators (e.g., net primary productivity for forest growth indicator; Table 2) to report at a relevant scale and in a cost-efficient and timely manner. Because of its national scope, Canada's National Forest Inventory (NFI, https://nfi.nfis.org) stood out as a keystone observation program from which information of interest for the Forest Change Tracking System could be extracted (e.g., forest growth; Girardin et al. 2016; Table 2). Other well-established monitoring systems, such as the computer-based Canadian Wildland Fire Information System (CWFIS; http://cwfis.cfs.nrcan.gc.ca), were instrumental in developing indicators related to fire (fire weather and fire regime; Boulanger et al. 2014; Table 2).

The spatial coverage of most Forest Change Tracking System indicators is national (Table 2). One exception is the indicator on tree mortality (Hogg et al. 2008; Michaelian et al. 2011; Table 2), as it is derived from the Climate Impacts on Productivity and Health of Aspen (CIPHA; http://www.nrcan.gc.ca/forests/climate-change/impacts/13119) project whose network of sites covers an area extending from southwestern Manitoba up to the southwestern forested part of the Northwest Territories. Another example is windthrow (Table 2), an important natural disturbance in shade-tolerant hardwood stands of North America (Bouchard et al. 2009; Girard et al. 2014), which was addressed over eastern Canada only (Saad et al. 2017) because of its potential increased importance in that region as tropical storms increasingly track along the eastern coastline.

The availability of historical records differs among indicators (Table 2). For example, 1950–2010 grids of daily minimum temperature were used to get estimates of growing season length across Canada (Pedlar et al. 2015), while 1959–2010 records from CWFIS were used to report on Canada-wide trends in annual area burned and numbers of large fires (> 200 ha; Boulanger et al. 2014). By contrast, permafrost records of 30 years are available at only a handful of sites, while continuous soil temperature measurements are available only from 2007 to 2014 and only for about 80 sites across the Canadian boreal and Arctic (permafrost indicator; Smith et al. 2012; Table 2).

Projections under specific climate scenarios are available for most indicators (Table 2; Fig. 1 for annual area burned) but are very uncertain for some. For instance, the annual number and cost of wildland fire evacuations (Hope et al. 2016; Table 2) are expected to rise with projected increases in the area burned. Yet, interannual variability in wildland fire activity is high and wildland fire evacuations depend on other non-climatic factors, such as population density and settlement patterns (Beverly and Bothwell 2011).

Data for published indicators are available through the Forest Change data catalog (http://cfs.nrcan.gc.ca/fc-data-catalogue). Users can have access to each map in PDF or to the data in shapefiles or raster format for the time period of interest. Adaptation tools and resources are also provided for each Forest Change Tracking System indicator. Website users can then understand where and how impacts are occurring and identify ways of addressing these impacts. For instance, SeedWhere is a tool that helps users match seed sources to planting sites under the current or a future climate.

3.2 Indicators under development

Additional indicators are currently under development (to be finalized before 2021; Table 2), but the absence or the non-standardized nature of some of the datasets across Canadian jurisdictions has delayed the development of several. For example, pest and pathogen data collected by different agencies require standardization before being presented nationally as incidence indicators (Table 2). Likewise, for indicators on tree regeneration (Table 2), there is currently no standardized protocol for data collection (Gauthier et al. 2014b). The TST and LEG are currently exploring the use of data from light detection and ranging (LiDAR) surveys or from enhanced stereo image processing techniques generated by provincial governments and individual companies.

Winter roads are very important for the forestry (Ogden and Innes 2007) and mining industries, as well as for remote northern communities in Canada. Anecdotal evidence suggests that the reliability of winter access over frozen ground or water is decreasing across northern Canada. The development of an indicator on freeze–thaw of winter roads (Table 2) is frequently requested by stakeholders through our regular surveys as an essential component of their adaptation planning process. Past data on winter roads are not forest-specific and vary according to Canadian provinces and territories. The use of indices (e.g., McKenney et al. 2013) and proxies of freeze–thaw events (Pedlar et al. 2015) to develop an indicator on freeze–thaw of winter roads (Table 2) is being explored.

There are also indicators of interest for which the CFS does not currently have the resources to develop (Table 2). For example, tree phenology (bud break, flowering, etc.) is highly climate-sensitive, notably to spring and fall temperature fluctuations (Beaubien and Hamann 2011; Cleland et al. 2012; Fridley 2012), but uncovering phenological trends requires many years of measurements at very specific times of the year and at different spatial resolutions. None of these activities are compatible with existing Canadian forest inventory systems (e.g., NFI). In this context, partnerships with non-governmental research groups are the most viable option for acquiring the data needed for indicator development.

4 The outlook of the Forest Change Tracking System

The Forest Change Tracking System website provides a variety of updatable, spatially explicit, extensive, and open-access information at scales relevant to address questions requiring regional to national analysis, such as forest management and international reporting. Maps and analyses indicating the rate of change and identifying areas experiencing or expected to experience high climate change effects can also inform adaptation measures, including the improvement of capacity for early detection and for proactive intervention to minimize potential negative consequences. From January 11, 2016 to October 17, 2017, visits to the Forest Change Tracking System indicator website generated 30,772 page views with an average time on a page of 5 minutes.

On a corporate basis, the development of a Forest Change Tracking System for climate change indicators has allowed the CFS to better address challenges associated with data standards and formats, data exchanges, and communication among researchers from different locations and disciplinary backgrounds. The program has also built a structured framework of knowledge generation and integration that enhances the efficiency and relevance of forest-related climate change research within the CFS and partner agencies through the creation of synergies, the clarification of priorities, and the identification of knowledge or capacity gaps. The Tracking System also formed the basis of a new CFS website to deliver forest adaptation information.

The Forest Change Tracking System addresses the need to provide climate change information to the Canadian public, as identified by the Commissioner of the Environment and Sustainable Development (CESDC 2010). It also responds to the request of policy makers and forest managers for information on the potential impacts of climate change that is needed to orient vulnerability assessments, risk analyses, and policy development (Johnston and Edwards 2013). In Canada's forest sector, vulnerability assessments and adaptation planning are at their early stages with some provinces and territories starting to alter policies and regulations to enable adaptation (Gauthier et al. 2014a; Le Goff and Bergeron 2014).

The Canadian Council of Forest Ministers (CCFM) provides a framework for the stewardship and sustainable management of Canada's forests and has recognized climate change as a priority for the sector (CCFM 2008). Collaboration between the CFS and the provincial and territorial forest agencies, either bilaterally or through the CCFM, promotes a common understanding and continued discussions around the adaptation issue (e.g., Edwards and Hirsch 2012; Gray 2012). Establishing and maintaining dialog with other forest sector-related players (e.g., municipalities, insurance and financial institutions, health and safety boards) has also enhanced the reach of climate change-related information and has benefited the Forest Change Tracking System through the better definition of demand for climate change information.

Important efforts were invested in building a digital support infrastructure to house the data and the interface for public access. Work is still needed to provide dynamic information and to allow for end-user input. Forest Change website development also has to address growing requirements related to cybersecurity and to new government standards currently being implemented. Search engines to mine our databases and features to pan and zoom from a national view to local scales across the country are being developed currently to meet the new demands. We are also working on making feedback possible to help us better meet end-user needs.

So far, Forest Change Tracking System activities have focused on the establishment of a framework for tracking forest changes across the country. Substantial progress now remains to be made on improving the accounting for and communication of uncertainties related to this climate change information (Charron 2014; Hawkins et al. 2016; Hawkins and Sutton 2009; Lemprière et al. 2008). To better equip decision-makers with the best knowledge, assessing and addressing this uncertainty is a priority. We are also working on the inclusion of causality as a key criterion of Forest Change Tracking System indicators; extracting the climate change signal from that of multiple stressors will better inform users about ongoing climate-related changes across Canadian forests.

Feedback from stakeholders has highlighted the need for local to regional information. This includes incorporating both detailed indicators that are relevant at regional scales but are unavailable nationally and indicators scalable at local to national scales and thus useful to any scale of decision-making. The CFS could benefit from national partnering with other organizations that can provide finer scale information to fill information needs and decision-making. Such tracking would also help identify areas at risk requiring targeted monitoring. Other actors within the forest sector, and in particular, the provincial forest management agencies, are aware of and, in some cases, are already documenting local issues related to climatic events and climate change. However, the very noisy nature of climate change impacts may hide trends at local levels over short time scales. Through its Tracking System, the CFS brings a national expertise and perspective to the identification, quantification, and projection of such impacts and aims to provide information to raise awareness and guide policy makers and forest managers.

The human system will likely respond to climate change in a less deterministic manner than the ecological systems. We are developing a better understanding of the spatial distribution and socioeconomic characteristics of populations within the forest-based communities and are using this information to improve our ability to identify vulnerabilities of the human system to climate change (Eddy et al. 2014). Efforts to understand, define, and track human indicators will be key for assessing adaptation success.

Forest Change Tracking System indicators and the underlying framework that has been developed offer new potential for alignment with other national or international initiatives through sharing of data, methodology, end-user needs, lessons learned, and even capacity. There is a potential for Forest Change to benefit from citizen science to gather and share information on forest changes. Several highly successful citizen science programs have been established in Canada, including the Alberta and Canada PlantWatch programs (Beaubien and Hamann 2011), the North American Breeding Bird Survey, the Christmas Bird Count, the Marsh Monitoring Program, and Plant Hardiness of Canada. Collaboration opportunities with such partners exist on an ad hoc basis and could be strengthened.

Increased partnerships with universities, federal departments, and other research-based organizations could facilitate the collection of standardized, long-term, and cost-efficient data on key forest indicators. By creating common tracking standards and protocols, and housing the information to be maintained and shared, the CFS could obtain further data directly relevant to its needs, while enhancing academic engagement and collaboration. Setting standardized protocols may identify alignment among interested groups, including non-Canadian ones. Common monitoring and reporting among organizations and across borders would help produce additional data for better understanding global change. Moreover, the will of many citizens to contribute to knowledge acquisition increases awareness of the effects of climate change on society.

5 Conclusion

One fundamental step to support climate change adaptation is the adequate tracking and reporting of climate change impacts. The approach used to develop the Forest Change Tracking System was to focus on a limited number of the most relevant indicators, build on existing capacity, and use remote sensing data to produce national information on current and future climate change impacts on Canada's vast forests, across provincial and territorial boundaries. This solid foundation supports other Forest Change work, such as the development of adaptation tools and the integrated assessment of combined effects of multiple climate-related impacts on Canada's forests and forest sector (Ste-Marie et al. 2015). Ongoing dialog with forest sector stakeholders is central to help Forest Change tailor its knowledge products to meet the sector's adaptation information needs, and support on-the-ground implementation. Adaptation indicators will also be required to determine whether implemented actions are successful so that continuous improvement can be integrated into the climate change adaptation process.

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