Canadian Council of Forest Ministers
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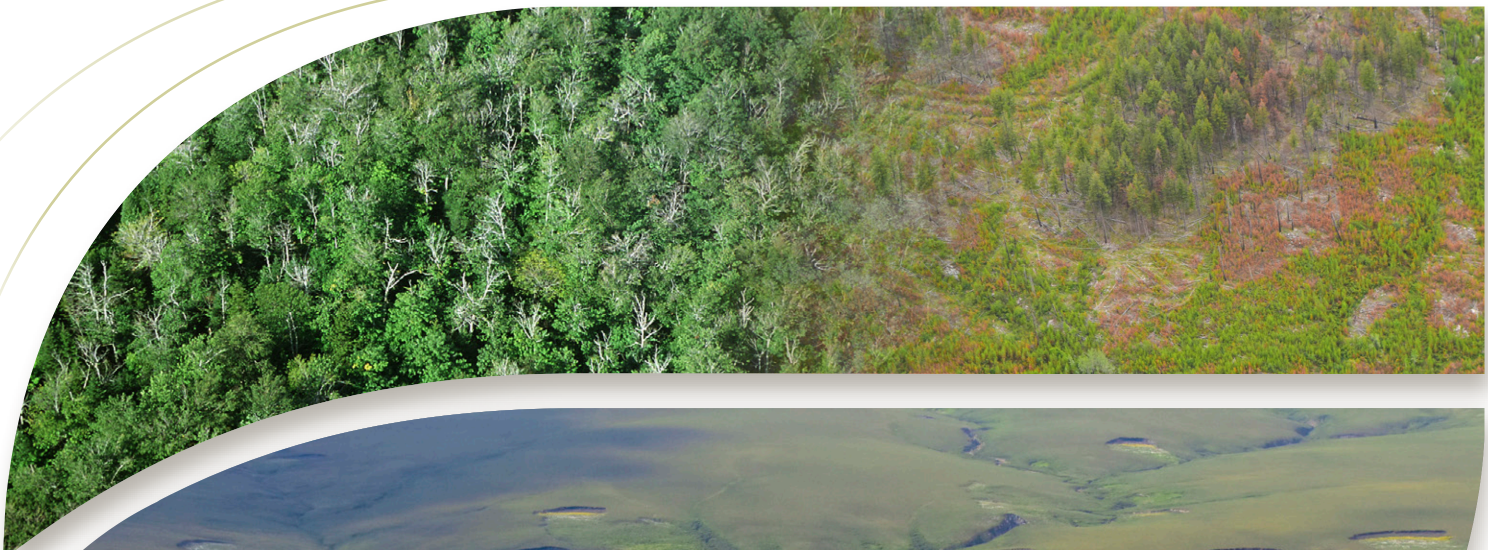
Vulnerability Assessment of Forest Health Monitoring Policies and Practices under a Changing Climate:

Adaptation, Implementation and Evaluation



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VULNERABILITY ASSESSMENT OF FOREST HEALTH MONITORING POLICIES AND PRACTICES UNDER A CHANGING CLIMATE:

Adaptation, Implementation and Evaluation

Prepared for the Canadian Council of Forest Ministers, Forest Pest Working Group

Janice Hodge, National Forest Pest Strategy Technical Coordinator

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Purpose and Outcomes

A vulnerability assessment of Canada's forest health monitoring (FHM) policies and practices was undertaken by the Forest Pest Working Group (FPWG) of the Canadian Council of Forest Ministers (CCFM) to determine if adaptation of FHM policies and practices is required in light of climate change. Vulnerability is defined as the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes; it is a function of the character, magnitude, and rate of climate change and variation to which its system is exposed, its sensitivity, and its adaptive capacity (Parry et al. 2007)[1]. The emphasis of this assessment was on the human adaptation aspect, not the biophysical. Hence, it does not address means to improve forest resilience to disturbances, but rather the collective ability to capture and report on those disturbances. This is commonly referred to as the "adaptive capacity".

The FHM system, for the purposes of this report, includes forest health monitoring of biotic, abiotic, and invasive alien pests by provincial, territorial, and federal governments, which varies across Canada. The assessment found that the FHM system was vulnerable to climate-induced changes in that the ability to meet forest health monitoring objectives would be compromised. This means that adaptation is required. This report outlines and discusses the components of the vulnerability assessment, including identification of adaptation options and implementation requirements.

[1] Parry, M.L., Canziani, O.F., Paultikof, J.P., van der Linden, P.J., Hanson, C.E. editors. 2007. Climate change 2007: impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge Univ. Press Cambridge, UK, and New York, NY.

Approach

This vulnerability assessment was conducted in two phases. In October 2016, a workshop was held to determine if forest pest monitoring policies and practices across Canada were adequate in light of anticipated changes to forest pest distribution, frequency, severity, and longevity (herein referred to as disturbance patterns) given a future climate change scenario. The workshop brought together provincial and territorial forest pest managers, Canadian Food Inspection Agency (CFIA) invasive species managers, and scientific support from CFS research scientists (Annex 1). In the fall of 2017, the same jurisdictions and agency (Annex 1) participated in several online surveys to prioritize adaptation options, identify implementation requirements, and identify a means to evaluate performance.

The assessment followed the framework outlined in the CCFM Climate Change Task Force (CCTF) guidebook for assessing vulnerability and mainstreaming adaptation into decision making (Edwards, Pearce, Ogden and Williamson, 2015)[2] (Figure 1).

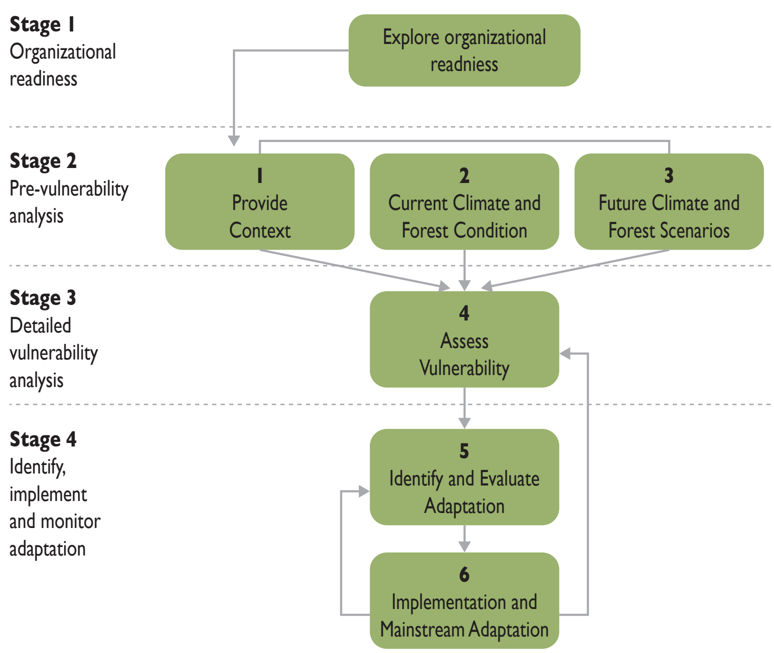

Figure 1. Stages and steps of a vulnerability assessment (Edwards et al. 2015).[2]

[2] Edwards, J.E., Pearce, C., Ogden, A.E., and Williamson, T.B. 2015. Climate change and sustainable forest management in Canada: a guidebook for assessing vulnerability and mainstreaming adaptations into decision making. Canadian Council of Forest Ministers, Ottawa, Ontario.

Context

Canada's vast and diverse forests are shaped by biotic and abiotic disturbances, including insects, diseases, and wildfires. For the most part, these natural disturbance events are cyclical and defined by their historical range of variability (HRV). HRV is dependent upon many factors, including climate patterns. Climate change is expected to modify HRVs and their impacts to varying degrees across forested ecosystems of Canada due to changes in forest pests' (and their natural enemies') distribution, frequency, and intensity, as well as host distribution, phenology, and health. As such, climate change is expected to increase the frequency and severity of disturbances, including abiotic disturbances, making forests more vulnerable and less resilient. This will lead to increased losses of forest and associated resource values and negatively impact their ability to meet sustainable forest management objectives or to supply goods and services.

Forest pest managers across Canada seek to minimize losses due to disturbances by using a variety of policies and practices, including monitoring and detection programs. These programs are key to effective forest pest management, as they identify forest pest risks and facilitate forest pest management planning and the implementation of hazard or risk reduction practices. The Provinces and Territories are responsible for designing and implementing these programs for native pests, and CFIA is responsible for regulated invasive alien pests with the following forest health monitoring objectives:

1. Detect and record biotic and abiotic disturbances to Canada's forest
2. Evaluate results to help improve understanding of hazard and risk
3. Help inform forest health management decisions

Impacts of climate change on forest conditions and processes and resultant changes to disturbance regime patterns will affect forest pest managers' abilities to achieve forest health monitoring objectives. Understanding how these objectives might be affected is critical in assessing the vulnerability of these objectives to climate change.

Monitoring efforts vary across Canada and tend to focus on managed forests with a known history of disturbances by major forest pests, many of which are defoliators. A few jurisdictions monitor both biotic and abiotic events across all forested areas. FHM monitoring consists of aerial and ground surveys to capture annual forest pest population fluctuations and location and severity of these disturbances. In some jurisdictions, FHM efforts vary according to the level of pest activity: intensity and distribution of surveys increases as pest level increases. In other jurisdictions, monitoring is conducted annually at the same intensity regardless of pest population levels. For example, Quebec (QC) has an extensive ground monitoring network that guides where aerial surveys are conducted, which means that aerial survey coverage can vary from year to year.

In 2012, the CCFM reported on forest health monitoring efforts across Canada and found that most surveys were directed at forest insect pests, such as defoliators and bark beetles, and less often at forest pathogens and abiotic disturbances (CCFM 2012)[3]. The report also found that 64% of managed forests are being monitored via aerial surveys, which represents 50% of the forested area across Canada. Monitoring gaps were identified in northern latitudes, deciduous forests and

[3] Canadian Council of Forest Ministers, 2012. Forest Pest Monitoring in Canada: Current situation, compatibilities, gaps and proposed enhanced monitoring program. Canadian Council of Forest Ministers, Forest Pest Working Group. Ottawa, Ontario. 42 p.

non-contiguous forest types, most of which are unmanaged forests. For the purposes of this vulnerability assessment, an updated survey of current FHM efforts was completed which found that 75% of managed forests is being monitored, which represents 61% of the forested land base (Figure 2). This 11% increase in area coverage was a result of an increase in eastern spruce budworm populations in QC that triggered additional aerial surveys, as well as expanded aerial surveys in Manitoba (MB).

A more recent (2015) CCFM internal report of Provincial and Territorial forest pest managers' perceptions, involvement, concerns and needs as they relate to climate change found that consistent monitoring and disturbance-related research were the most important aspects of addressing climate change-related forest health issues. Yet, most reported lack of consistent funding and limited or inconsistent monitoring. These results triggered the need to characterize the risk to current forest health monitoring policies and practices and their ability to inform effective pest management under a future climate change scenario.

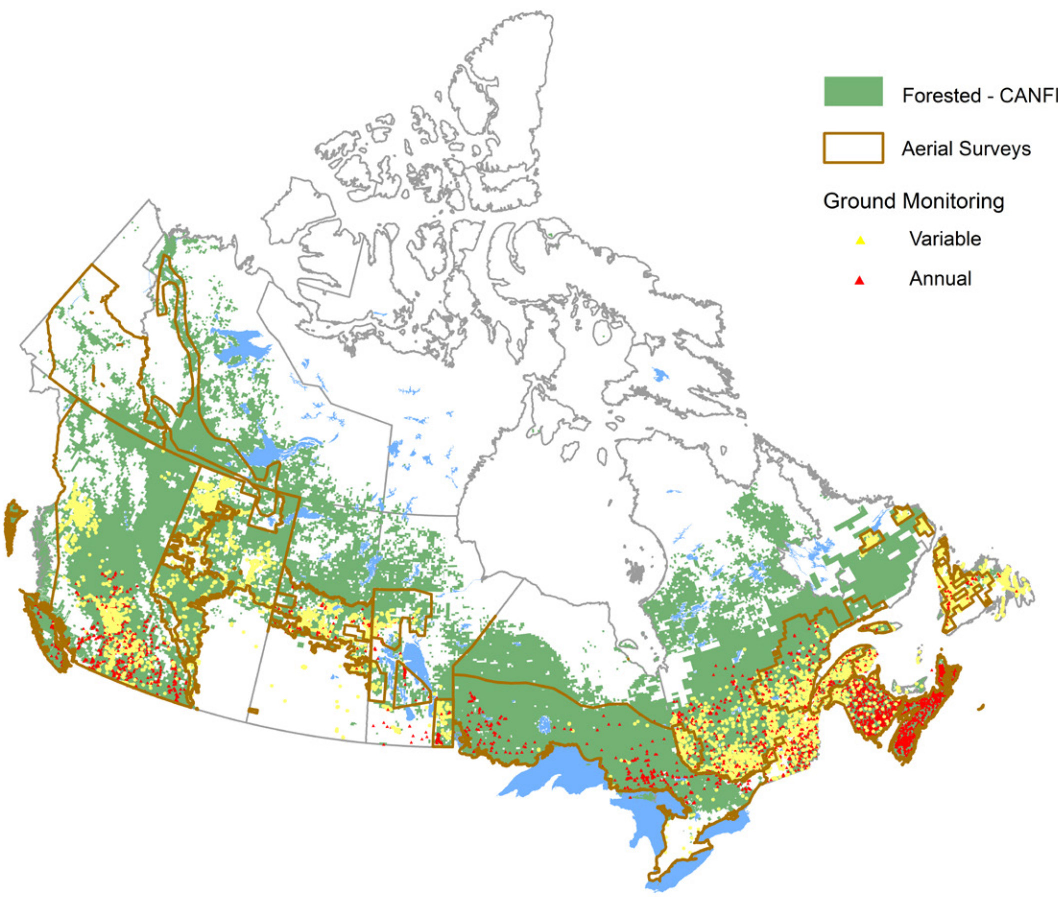

Figure 2. Location of FHM ground plots and extent of aerial surveys across Canada, 2016.

Forest Pests Under Current and Future Climate

The purpose of this section is to document forest pest conditions under current and future climate. Not only does this serve as a baseline for comparison of a future climate scenario, but it also helps provide a better understanding of the relationship between current and future climate and resultant forest pest conditions. The outcome of this exercise is an assessment of the current and anticipated future changes to disturbance regime patterns, e.g. distribution, frequency, and severity.

CURRENT FOREST PEST CONDITIONS

Climate-related changes in forest pest patterns or disturbance regimes (e.g. distribution, severity, or frequency) have already been observed for several forest pests. Most notable is that of the mountain pine beetle, which is now established in novel forests of Alberta (AB) and continues to move eastward and northward, albeit slowly. Table 1 summarizes some of the other observed changes in pest patterns. It is important to note that this exercise was not meant to capture all of the changes, but rather to serve as an indicator of changes in pest patterns that have already occurred as a result of changing climate, and as a baseline for the future climate scenario.

FUTURE FOREST PEST CONDITIONS

The purpose of this step is to characterize anticipated changes in pest patterns under a future climate change scenario and to assess the anticipated disturbance regime impact. The climate change scenario selected is a blended General Circulation Model Representative Concentration Pathway 8.5 (RCP 8.5) and is one of the greenhouse gas concentration scenarios adopted by the Intergovernmental Panel on Climate Change. RCP 8.5 assumes that greenhouse gas emissions will continue to rise throughout the 21st century. The rationale for selecting this scenario is to get an idea of the range of possibilities under a business-as-usual, "worstcase" scenario. This will also provide a better understanding how our current monitoring efforts compare to those forecast by the "worstcase" scenario. Under this scenario, if all measures were put in place now to reduce greenhouse gas emissions, it is expected that there would be no significant changes in carbon levels until 2050 onwards. Climate during the 1961-1990 time period was selected as the baseline or "normal" period, as there is a high likelihood that climate was already influencing disturbance patterns in the next normal period (1971-2000).

This scenario indicates an overall increase in temperatures, with higher increases in the north, as well as a higher frequency of extreme weather events (Figure 3). Changes in precipitations are less clear, e.g. more uncertain, particularly as they pertain to seasonality; however, one certainty is that precipitations are projected to increase nationwide (Figure 4). Increased temperatures will: 1) lead to an increase in absolute humidity, thereby increasing precipitations; and 2) increase evaporation rates leading to increased frequencies and intensities of drought. It is possible that in any given year or season, these two effects may offset each other somewhat.

Temperature increases will lead to changes in forest insect distribution, development and winter mortality rates, dispersal, voltinism, and fecundity. Temperature changes will also affect host phenology and resistance, as well as levels of natural enemies. The degree to which these will affect pests, hosts, or natural enemies is highly uncertain given that some changes will be beneficial while others will be detrimental. For instance, higher winter temperatures could lead to lower overwintering mortality rates for southern species such as southern pine beetle and non-diapausing species such as mountain pine beetle, but could be detrimental to other species such as eastern spruce budworm. Pests with no diapause requirements could undergo rapid range expansion, whereas those with low temperature requirements may experience range contraction. Changes in forest pest diseases are more uncertain, with the potential for more frequent and intense foliar disease outbreaks and abiotic events. Table 1 summarizes some of the anticipated future changes to forest pest disturbance patterns with a high degree of uncertainty due to: 1) the lack of location-specific climate predictions in some areas; and 2) species-specific responses to these changes, which may be negative or positive depending on the degree of climate change.

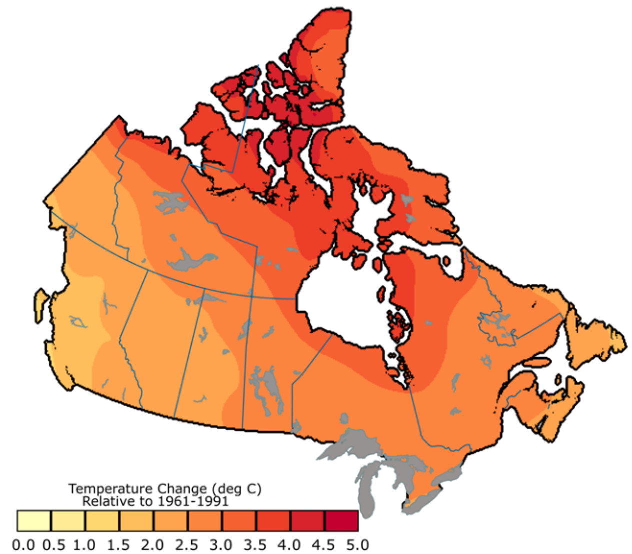

Figure 3. 2011-2040 projected change in annual mean temperature (° Celsius) under the RCP 8.5 scenario relative to the 1961-1991baseline. Projected mean temperature is an average of four global climate models (Source: Natural Resources Canada)

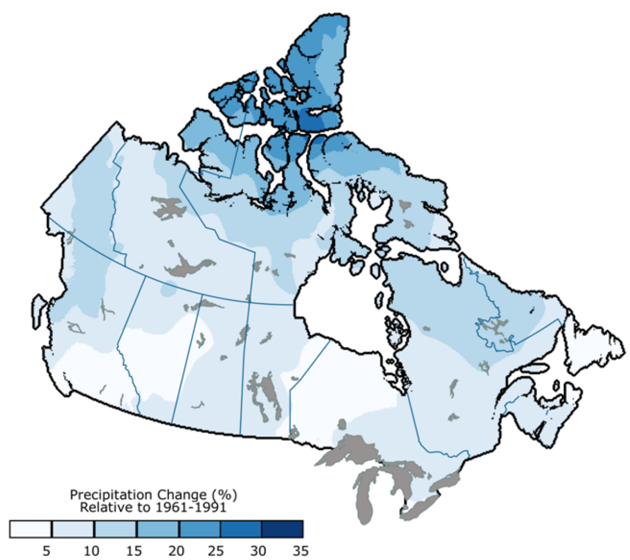

Figure 4. 2011-2040 projected percentage change in annual mean precipitation under the RCP 8.5 scenario relative the 1961-1991 baseline. Projected mean precipitation is an average of four global climate models.

Table 1. Current (observed) and future (anticipated) changes in pest patterns.

Pest Group	Pest	Current changes in pest patterns	Future changes in pest patterns
Biotic	Mountain pine beetle	Northern and eastern expansion of known historical range – established in AB	Continued northern and eastern expansion
	Eastern spruce budworm	Northern expansion of known historical range in QC and Mackenzie Delta	Continued northern expansion, southern contraction, increased fuels hazards, increased incidence on black spruce
	Eastern hemlock looper	• Possibly range expansion in QC but may be part of "normal" cycle • Northern range expansion in Newfoundland and Labrador (NL)	Continued range expansion in QC Potential for higher overwinter mortality in southern portions of NL
	Drought/dwarf mistletoe complex	Lodgepole pine dwarf mistletoe mortality induced by drought in northern AB	Increase in drought events may lead to increase in mortality due to mistletoe
	Foliar diseases	Higher incidence, severity and mortality by *Dothistroma septosporum* in BC and AB	Increase in incidence and severity of all foliar diseases
	Armillaria root disease	Increased incidence and mortality in balsam fir in AB	If abiotic stresses such as drought are contributing factors, then ongoing and increased mortality is expected
Invasive	White pine blister rust	Increased incidence in higher elevations on whitebark pine	Northern expansion and higher elevations
	Hemlock wooly adelgid	Northern expansion from United States into southern Ontario (ON) and Nova Scotia (NS).	Increased potential for establishment
	All	• Gypsy moth – Positive catches in northern AB (Fort McMurray) 2 years in a row (not established) • Banded elm bark beetle – Established in Saskatchewan (SK) and expanding into AB • Small European elm bark beetle – More frequently detected in southern SK • Satin Moth - Newest forest insect pest in the City of Edmonton in the last 20 years • Psyllid on black ash – Widespread mortality of black ash in the City of Edmonton • Balsam woolly adelgid range expansion further north and east from known infestations in south coastal BC • New detections of emerald ash borer; New Brunswick (NB) and NS (2018), MB (2017)	Increased potential for establishment of invasive species Change in transportation corridors resulting from climate change could change entry points which will influence FHM practices Range expansion of already established invasive species

Pest Group	Pest	Current changes in pest patterns	Future changes in pest patterns
Abiotic	Aspen decline	Persistent and expansive in Yukon (YT) and southern Northwest Territories (NWT); also observed in AB	More persistent and expansive; cumulative impacts from pest complexes
	Drought	Observed in many jurisdictions over the last 2 decades; NWT drought-related damage to jack pine and white spruce regeneration, higher incidence of white spotted sawyer beetle attacked drought stressed tree, and trigger for expansive forest tent caterpillar outbreak Increased mortality of plantations (new and established regeneration) in Southern BC	Increase in incidence, severity and extent
	Temperature extremes		High temperature extremes for 3-4 weeks are detrimental to trees and could lead to increased mortality and increase in secondary pests
	Temperature increase		Will lead to melting of permafrost thereby increasing flooding in valley bottoms and possibly drought stress on higher elevation sites
	Fire		Increase in fire due to drought could lead to an increase in pests
	Windthrow	Increased frequency in SK – wind disturbance monitoring is now being conducting as a result	More likelihood of extreme wind events leading to an increase in spruce beetle, Douglas-fir beetle, Ips, and other secondary pests. Also lead to an increase in fuel hazards
	Permafrost Subsidence / Flooding	Drunken forest in muskeg and peat plateaus observed the NWT – black spruce most frequently affected	Continued and with higher impacts

Vulnerability Assessment

Vulnerability in the context of this assessment is based on the ability to achieve FHM objectives as well as adaptive capacity to adjust to climate-induced changes. Adaptive capacity is influenced by a number of factors including awareness, knowledge and human capital, institutions and governance.

The overall adaptive capacity of the FHM system is viewed as inadequate due to a lack of awareness, poor communication, uncertainty associated with climate change, lack of tools and directed research, lack of human and financial resources, institutional resistance to change, and a lack of flexible and proactive management policies (Table 2).

Table 2. Adaptive capacity concerns and needs by topic area.

Awareness and understanding of climate change and perceptions of climate change risk
Low awareness amongst senior managers
Poor communication between scientists and policy-makers
Knowledge capital (science, information, knowledge exchange, and technology)
High level of uncertainty regarding pest and disease dynamics, which could be reduced with analysis of existing forest pest data
Lack of risk knowledge, cost/benefit analysis, and information sharing
Support and development of climate change tools, e.g. BioSIM[1]
Directed research to identify effects of climate change on major forest pests including changes to seasonal phenology and development, survival rates of various life-stages, and impact on natural controls.
Human capital
Lack of fiscal and human resources, including trained personnel, both with regard to recognition and identification of biotic and abiotic disturbances but also to climate change signatures
Succession planning is required
Lack of taxonomists
Support and development of climate change tools, e.g. BioSIM
Institutions
Current forest health monitoring is not sufficient; often confined to managed or commercial forests
Current and future human and fiscal resources are not adequate
Lack of funding for standard operating procedures
Lack of an integrated approach to forest health monitoring
Risk aversion – general inertia and institutional resistance to change
Bureaucratic hurdles
Need to spend more on planning with regard to climate change
Good at monitoring known major pests but not so much for other less major pests and diseases
Inter-provincial consistency in monitoring is an issue
Need to look at current monitoring methods for known major pests in light of results of directed research on effects of climate change (see knowledge capital) and modify monitoring methods as needed
Resource governance dynamics and institutional change
Policy not flexible enough, particularly for situations which may evolve quickly and in areas in boundary jurisdictions
Management tends to be adaptive somewhat to reactive but not proactive
Challenges with governance models

[1] BioSIM is a software tool designed to assist in the application of temperature-driven simulation models in pest management. It can also be used as a tool in the development and analysis of such models for purposes of scientific investigation.

Given current and future biotic and abiotic conditions and adaptive capacity concerns, the ability to meet FHM objectives will be compromised, thereby making the FHM system vulnerable (Table 3). As a result, adaptation of FHM policies and practices is required to help improve resilience of the FHM system.

Table 3. Current and future vulnerability as a function of adaptive capacity and ability to achieve forest health monitoring objectives.

Forest Health Monitoring Objectives		Current Forest Pest Condition		Future Forest Pest Condition	
	Adaptive capacity	Ability to achieve FHM objective	Vulnerability	Ability to achieve FHM objective	Vulnerability
Detect and record biotic and abiotic disturbances to Canada's forest.	Low to moderate	Low	Moderate	Low	Moderate
Evaluate results to help improve understanding of hazard and risk.	Low to moderate	Low	Moderate	Moderate	Moderate
Help inform forest health management decisions.	Low to moderate	Low to Moderate	Moderate	Moderate to High	High

Adaptation Options

Adaptation refers to activities or actions undertaken to reduce the vulnerability of the FHM system to climate-induced changes. Fourteen adaptation options were identified to build or enhance adaptive capacity.

1. Incorporate or develop new technologies into monitoring, including remote sensing, molecular diagnostic tools, forest health diagnostic applications, and decision support systems.
   - Remote sensing usage could be increased beyond areas currently not being monitored as effectiveness improves.
   - Forest health applications (e.g. apps) should have the ability to provide both diagnostic capabilities and uploading abilities in order to build or enhance the underlying database by sharing photos, location information, etc. Potential software: ArcGis Survey.
   - Decision support system for prioritization of monitoring activities.
   - Use of BioSIM to look at insect survival and year-to-year survival rates.

2. Adopt proactive forest health monitoring principles by extending current monitoring policies and practices to include all disturbances (not just major pests).
   - Establish forest health monitoring plots to detect change and to better understand the hazards and risks of known and unknown forest health risks, including the cumulative effects of abiotic events (e.g. drought) on forest pests. Alternatively, piggyback on existing growth and yield plots, provided that individuals assessing plots have the appropriate forest health training.
   - Develop and implement a national stratification regime and change detection sampling protocol for forest health monitoring plots.
   - Develop standardized monitoring survey protocols for pests currently being monitored across Canada, including use of similar pheromones.
   - Develop standards for identifying abiotic and decline complexes.
   - Mainstream forest health into other aspects of forest management, including growth and yield plots, using the national change detection sampling protocol noted above.

3. Gain a better understanding of the best use of dwindling resources and where we can make the most efficacious gains. Determine acceptable levels of forest health monitoring.

4. Promote the need for, or maintenance of, internal forest health research capacity. Where capacity is lacking, promote priority research needs with academia and other research organizations to help develop or improve existing monitoring and detection tools.
   - » Assess whether the USFS model is suitable and realistic for Canada where CFS would provide research and development for standardized detection tools.
   - » Improve access to existing expertise.

5. Adopt an integrated approach to address human capacity concerns that builds on existing internal capacity, provides resource-sharing opportunities with other jurisdictions or agencies, and incorporates capacity from citizen science groups, all forestry stakeholders, and Entomological Societies, and list serves. Existing gaps include diagnosticians, taxonomists, and CFIA inspector. Future needs could include personnel required to manage the citizen science aspect and to respond to public forest health concerns).
   - » Implement successional planning and provide mentoring and training opportunities where they exist.
   - » Assess whether a revisit of the Canadian Interagency Forest Fire Centre resourcesharing framework is required.
   - » Develop applications ("apps") and related tools to support citizen science groups.

6. Develop a communications or similar strategy to raise awareness of both internal and external audiences on: 1) existing forest health monitoring programs and tools and potential opportunity to include some aspects of climate change monitoring into this program; and 2) potential impacts to forest health and associated resources, including carbon, due to climate change. This could also help individual jurisdictions build a forest health monitoring business case. Objectives would include, but are not limited to, the following:
   - » Provide senior managers and science and policy makers a better understanding of the link between climate change and forest health, and familiarize them with the forest health monitoring techniques, including the pros and cons of remote sensing and citizen science groups.
   - » Promote the value of forest health monitoring rather than the need for it, including remote northern locations.
   - » Engage the public in soliciting political support for effective forest health monitoring;
   - » Inform border inspection facilities of forest pest climate-related risks.
   - » Inform all stakeholders, including the public, on global forest health climate-related issues.

7. Determine if there is a reasonable means of identifying disturbance pattern changes due to climate change versus natural population variation.

8. Promote the use of the Pest Strategy Information System to provide timely monitoring results between jurisdictions, agencies, and external stakeholders and that builds on existing information and communication systems.

9. Improve communication with science and policy sections by identifying, clarifying and communicating roles and responsibilities with regard to forest health and climate change in federal and provincial and territorial systems and within jurisdictions.

10. Ensure that forest health is an integral component of sustainable forest management and promote the idea that forest health funding should be derived from forest management sources (e.g. portion of stumpage allocated to forest health). In the development of such a funding tool, lessons learned from jurisdictions having employed such a system should be sought.

11. Promote the value of historical CFS Insect and Disease Survey information and, where available, analyze this historical dataset to help inform current monitoring practices and identify potential climate-induced changes to disturbance patterns.

12. Evaluate the level of forestry curriculum in universities across Canada and develop a plan to address gaps if required.

13. Promote the inclusion of forest health in school curriculum, including the development and supply of educational materials. Consider using an approach similar to that adopted by some ON municipalities that provide funding to support urban forest health education to grades 1-12. This will provide for a long-term culture shift in the value of our urban and natural forests.

14. Identify a "champion" to promote ideas, both outwards and upwards.

PRIORITY ADAPTATION OPTIONS

A Delphi process was used to prioritize adaptation options; four were deemed a priority based on the natural breaks in the ranking (Table 4), with two rounds of the Delphi process achieving a strong level of consensus (degree of concordance).

Table 4. Adaptation options rankings based on two Delphi survey rounds – top four adaptation options highlighted in grey.

Adaptation Option (Abridged version)	Ranking	# of Top 5 Votes
Integration and development of new technologies	1	12
Adopt proactive forest health monitoring policies and practices which include all disturbances (not just major pests)	2	11
Identify acceptable monitoring levels and efficiencies	3	12
Promote research needs and maintain existing capacity	4	10
Adopt an integrated approach to address human capacity concerns	5	6
Develop a communication strategy	6	2
Determine if there is a means of identifying disturbance pattern changes due to climate change vs natural population variation	7	3
Promote the use of the Pest Strategy Information System (PSIS) to provide timely monitoring results	8	0
Improve communication with science and policy sections	9	1
Ensure forest health is an integral component of sustainable forest management	10	2
Promote the value of historical FIDS information	11	1
Evaluate the level of forestry curriculum in universities across Canada and develop a plan to address gaps if required	12	0

Adaptation Option (Abridged version)	Ranking	# of Top 5 Votes
Promote the inclusion of forest health in school curriculum	13	0
Identify a "champion" to promote ideas outwards and upwards	14	0
Degree of Concordance (Kendall's W Statistic)	0.73	
Degree of Concordance Rating	**Strong**	

Implementation of Priority Adaptation Options

An online qualitative survey was developed to collect information regarding implementation at a jurisdictional or agency level. The questions were based on those suggested in the CCFM Climate Change Task Force guidebook[2] and included the following topics:

- identification of who will be responsible for implementation;
- existing practices;
- opportunities to mainstream into existing business processes;
- changes to governance;
- resources, support, and operational changes/needs required to proceed;
- means to evaluate performance; and
- indicators of successful implementation.

As with any qualitative survey, the responses varied based on the experience and background of the respondent as well as on differences in monitoring programs and mandates. As such, it is important to bear in mind that jurisdictional differences do not necessarily imply that they do indeed differ; it could merely reflect a difference in respondent experience or background.

While the survey gathered a great deal of information, some aspects had more consensus than others and some had more relevancy to the question at hand. As the intention of this project is to develop a national picture, the topics were summarized according to the following guidelines:

- For topics where there was a general consensus, a national summary of the relevant findings is presented without reference to any jurisdiction.
- For topics which varied in their response, a summary is presented followed by a list with jurisdictional nuances.

Implementation of the top four adaptation options will require: 1) changes to policies or regulation, planning, protocols and methods; 2) development and delivery of training; 3) investments in technologies; 4) internal or external support; and 5) financial and human resources. The amount of change is dependent upon the adaptation option and will vary by jurisdiction.

Additional benefits of implementing adaptation options include informing other aspects of forest management planning including silviculture, timber supply modeling, habitat modelling, ecological classifications and services, and pest hazard and risk ratings. Adaptation options which require shared investments (e.g. remote sensing) or collaborative efforts will also complement multiple objectives. In essence, any new knowledge gained from FHM practices will improve the understanding of other aspects of ecosystem function and help to achieve other sustainable forest management objectives.

The next section summarizes implementation requirements for each priority adaptation option. Existing practices are summarized in Annex 2 and responsibility for implementing each adaptation option is provided in Annex 3.

ADAPTATION OPTION NO. 1: INTEGRATION AND DEVELOPMENT OF NEW TECHNOLOGIES

Incorporate or develop new technologies into monitoring, including remote sensing, molecular diagnostic tools, forest health diagnostic applications, and decision support systems.

Adaptation measure examples provided during the workshop included the following:

1. Remote sensing for areas not currently being monitored
2. Forest health diagnostic applications (e.g. apps)
3. Decision support systems for prioritization of monitoring activities

MAINSTREAMING OPPORTUNITIES

The majority of jurisdictions felt there were opportunities to mainstream new technologies into existing monitoring systems. New technologies will provide for expanded or improved monitoring but also facilitate: 1) harmonization of new technology tools and methods; 2) more timely incorporation into Decision Support Systems (DSS); and 3) better ability to share information with other departments or jurisdictions. New technologies in general are easily incorporated into existing FHM systems. Remote sensing will complement existing forest health monitoring by filling gaps in northern and remote areas, while diagnostic applications and tools could supplement existing forest health surveys. Other comments included:

- There is an increased willingness to incorporate new monitoring technologies into regular business processes. New technologies could also facilitate better alignment with processes used by other groups in Canada. (CFIA)
- Field applications could provide for more timely incorporation into DSS and better information sharing with other departments. (NS)
- We already have an extensive forest health monitoring program and forest inventory program (NB).
- Climate-related damage identified in remote sensing could be incorporated into existing provincial forest health conditions reporting. (BC)
- Remote sensing results could also form part of forest inventory growth and yield programs. (NWT)
- Conducting a small test run could expedite the use of remote sensing into regular business practices, and would help address current monitoring gaps. (MB)
- Satellite imagery and molecular identification tools for mushrooms have already been integrated into forest insect and disease survey activities. (QC)

IMPLEMENTATION REQUIREMENTS

GOVERNANCE

A few jurisdictions expressed concerns regarding who would be responsible for remote sensing development and application costs in areas outside their traditional monitoring areas. This may require a change in policies in some jurisdictions. NB also expressed a need to remove legislative barriers to using Unmanned Aerial Vehicle (UAV) for forestry applications.

RESOURCES AND SUPPORT

Human and Financial Resources

Investments into remote sensing data acquisition, interpretation, maintenance, and equipment would be required for those jurisdictions interested in using remote sensing technology. Investments will also be needed to develop and maintain selected new technologies and to incorporate them in day-to-day activities related to monitoring.

The requirements for human and financial resources varied across jurisdictions, with some requiring full resourcing (BC, MB), others partial (SK, ON, NB, NS, CFIA, NWT), and others uncertain (NL). All will require funding for new technologies training.

- Only a few jurisdictions reported that they have in-house remote sensing expertise. (NB, SK)
- A remote sensing analyst would need to be contracted for remote sensing products, as would as a skilled analyst familiar with forest health identification. (NWT)
- External resources are required for application development. (SK)
- Existing personnel who conduct monitoring could be used for implementation of new technologies but would require additional resources in the long-term. (CFIA)
- Financial resources are required. (YT)
- Requirements will depend on what is involved with implementation. (NL)

Support

Internal

Most jurisdictions indicated that internal support would be required from senior management or Assistant Deputy Ministers, with a few suggesting that cost/benefit analysis or endorsement from program specialist may also be required, particularly for remote sensing.

Internal staffing support or access to specialists varied and included:

- Forest Health and Adaptation staff with assistance from other departmental staff. (AB)
- Staff specialists (internal) and potential users of the information would have to be engaged and consulted for development, buy-in, and eventual consumption of the product. (BC)
- Involvement of Communication Branch for external development of diagnostic applications. (SK)
- Primarily internal; would need training with operational staff and specialists. (NB)
- Internal buy-in from Director or above, such as Assistant Deputy Minister or Minister (YT)
- Most cases internal support is sufficient. (NS)
- Internal staff and external contracted advisors/consultants would have to be involved in the implementation process. (NWT)

External

External support needs varied and included the following:

- Potential users of the information would have to be engaged and consulted for development, buy-in, and eventual consumption of the product. (BC)

- Molecular analysis for the identification of pathogens requires collaboration between QC's Forest Pest Management Service of the Ministère des Forêts, de la Faune et des Parcs du Québec and Laurentian Forestry Center, Natural Resources Canada. (QC)
- If a national forest health diagnostic application was considered for development, it would require buy-in from other jurisdictions. (NL)
- Additional partners/end users to help justify purchase and maintenance of remote sensing. (SK)
- As a regulatory agency, CFIA may need to ensure that new technologies are recognized and approved by trading partners. (CFIA)

OPERATIONS

Protocols and Guidelines

Protocols and guidelines will be required prior to implementation. Their development will require input from jurisdictions to ensure that outputs of new technologies, like remote sensing, meet their needs. Conversely, existing monitoring protocols may have to be modified to take into account the requirements of new technologies. A few jurisdictions suggested that the development of remote sensing protocols or diagnostic applications should be coordinated at a national level to enable harmonization of methods across jurisdictions.

Training

Once protocols and guidelines for new technologies are established, training materials will be required, as will delivery of training on their operational use.

- BioSIM for DSS requires training and continual regional validation. (NS)

Other

An evaluation of existing forest heath diagnostic applications should be considered to potentially develop a national diagnostic application. Features and characteristics should be compatible with the National Forest Pest Strategy Information System to facilitate uploading of data. (NL)

SUCCESSFUL IMPLEMENTATION INDICATORS

Successful implementation indicators varied by technology, some being very broad in nature while others were more specific.

NEW TECHNOLOGIES IN GENERAL

- Incorporation of information obtained from new technologies into the management of forest resources for industry and the public. (AB)
- Annually updated database with meaningful and accurate descriptors of the forest condition for the entire province, and that individuals measuring stand health can identify forest health causal agents. Procedures are such that all parameters for assessing stand health are captured in one visit. (NB)
- The use of new technologies in routine monitoring, ensuring that new tools are complementary to other organizations. (CFIA)
- Various tools (apps, etc.) are being used to maximize the likelihood of early detection and to manage pests. (CFIA)

- A dedicated employee specializing or trained in BioSIM and DSS models. Ultimately, implementation of applications used for data collection/sampling and information dissemination in real-time to incorporate into models. (NS)

REMOTE SENSING

- Supporting research in the use of remote sensing in areas that are not covered by aerial surveys, like the Peel watershed. (YT)
- Aerial overview of priority areas in order to inform the next step: interpretation of issues observed in remote sensing. (NWT)
- Completion of a small test project to assess cost/benefits of use, and if beneficial to broadened to a provincial scale. (MB)
- Provision and use of remote sensing results in areas that are currently covered by conventional monitoring practices and those that are not. Also training for damage interpretation. (NL)

DIAGNOSTIC APPLICATIONS

- Successful deployment of a diagnostic application via website, workshops, or training sessions. (BC)
- Supporting the development of a national diagnostic application. (YT)
- Successful implementation would likely be improvements in real time diagnostic ability so that management decisions can be considered. (SK)
- Use of diagnostic applications (ON) with advanced capabilities by forest pest specialists and a standard version for non-forest pest personnel. Diagnostic tool should have a high degree of confidence. (NL)
- Implementation of applications used for data collection/sampling and information dissemination in real-time to incorporate into models. (NS)

ADAPTATION OPTION NO. 2: ADOPT PROACTIVE FOREST HEALTH MONITORING POLICIES AND PRACTICES

Adopt proactive forest health monitoring principles including extending current monitoring policies and practices to include all disturbances (not just major pests).

Adaptation measures examples provided during the workshop included the following:

- Establish forest health monitoring plots to detect change and to better understand the hazard and risk of known and unknown forest health risks, including the cumulative effects of abiotic events (e.g. drought) on forest pests.
- Mainstream forest health into other aspects of forest management, including growth and yield plots, using the national change detection sampling protocol noted above.

It should be noted that this adaptation option does not form part of CFIA's mandate.

MAINSTREAMING OPPORTUNITIES

Several jurisdictions have already integrated a forest health component into growth and yield or inventory plots (Annex 2). For those that have not, the possibility of doing so existed either internally or by means of changing requirements within Forest Management Plans for areas-based tenures.

One jurisdiction cautioned that growth and yield programs have recently experienced reductions in program support, and hence may not be the most appropriate. Other comments included:

- The establishment of long-term plots dedicated specifically to forest health is being considered. (AB)
- Forest industry partners should make forest health and climate change monitoring a best management practice which could be mainstreamed into their planning and operations work. (AB)
- The use of existing plots is being considered, as well as adding others under the integrated monitoring framework under development in ON. (ON)
- Work is being done towards the inclusion of monitoring pests within an established network of forestry permanent sample plots that monitor forest ecosystem succession, growth, and yield. (NS)

IMPLEMENTATION REQUIREMENTS

GOVERNANCE

Only AB provided a specific example relevant to governance, namely the need for forest industry to consider climate change and the uncertainty it introduces to components of their Forest Management Plans, including growth and yield projections. Including a forest health monitoring component into any forest inventories or assessments should become a best management practice for the forest industry. NL also noted that it would require a major shift in planning, procedures, policies, regulations and operational methods.

RESOURCES AND SUPPORT

Human and Financial Resources

Some jurisdictions indicated that they have limited capacity and that resources would have to be secured (SK, MB, NL, NWT), while others indicated they have some internal capacity (QC, NB, ON, BC, NS) but that additional resources would be required (AB, NB, ON, NS). Other comments included:

- Review and analysis of data to link climate change with forest damage will require specialists' time and perhaps consultant/contracting resources. (BC, NWT)
- Plots are being funded through the Land Based Investment Strategy inventory for the foreseeable future and managed by Forest Analysis and Inventory Branch. (BC)
- Dedicated staff would be required to develop monitoring principles and protocols, and funding would be required to ensure monitoring plots are established and maintained as per protocols. (AB)
- Research funding will also be required in order to better understand the cumulative effects of climate on host/pest interactions, as well as potential pest risk analysis funding. (AB)
- Partnerships would be considered. (SK)
- Training and revision of exiting protocols/guidelines will be required. (NB)

Support

The majority of jurisdictions indicated they would require internal (operational staff, specialists, senior management) or external (involvement or buy-in form other organizations) support for implementation.

Internal

Comments specific to internal support included:

- Senior management support is necessary for implementation to proceed (AB, NL, SK); may need to be convinced that investment is worth it. (NB)
- Maintaining monitoring plots requires an investment in specialist time to provide training and quality assurance and quality control. (BC)
- Review and analysis of data to link to climate change will require specialists' time and perhaps consultant/contracting resources. (BC)
- Uncertain – will be determined by the Biodiversity and Monitoring Section of Ministry of Natural Resources and Forestry (in collaboration with others). (ON)

External

Comments specific to external support included:

- Will require working more closely with Agriculture and Environment and Parks (particularly climate change office) for data sharing, trend analysis, risk analysis, etc. (AB)
- Given the potential magnitude of this project, external support and buy-in is critical, as is a culture shift. (AB)
- Industry partners could accept responsibility to monitor and survey for forest health agents as well as recognizing potential effects of climate change and related uncertainty in their planning and operations. (AB)
- In QC where this initiative has been undertaken since 2001, coordination was required between the Forest Pest Management Service and the Ministère des Forêts, de la Faune et des Parcs Forest Research Branch for the establishment of permanent plots. (QC)
- Would require involvement and buy-in from other jurisdictions. (NL)
- Expanded monitoring will require diagnostic support. (NWT, SK)

OPERATIONS

Planning or Procedures

The only specific comment regarding planning was from AB, which noted planning would have to become more proactive, rather than reactive, and that it should recognize the uncertainty associated with climate change impacts. This extends to industry, which currently has no legal requirements for monitoring the effects of climate change on forest health. NL commented that this adaptation would require a major shift in planning, procedures, policies, regulations, and operational methods.

Protocols and Methods

Forest health monitoring protocols that incorporate climate change uncertainty will have to be developed (informed by Adaptation Option No. 3 and Adaptation Option No. 4). Certain aspects could build on those which are already in place in jurisdictions that are addressing aspects of this adaptation. Ideally, protocols will define baseline monitoring: what and when to measure, frequency of measurement, and resolution of measurement. In QC where PSP's are already established, historical observations have guided the development of sampling methods and timing. Methods/

protocols/forms will have to be adjusted accordingly in instances where forest health is already incorporated into inventory or growth and yield plots.

Training

Once monitoring protocols are established, training materials, and delivery of training will be required.

SUCCESSFUL IMPLEMENTATION INDICATORS

- Proactive forest health monitoring principles as standard operating practices for government, industry, and other stakeholders. (AB)
- Climate change considerations in natural resource management planning and operations. (AB)
- An established and maintained network of monitoring plots providing climate change impact data on forest conditions. (BC)
- Regular reporting of Young Stand Monitoring forest health data results and implications. (BC)
- Expanded network of aerial and ground surveys. (ON)
- Identification of stress factors and impacts on the forest condition at any point in time, allowing for better resource management. (NB)
- Establishment of forest health monitoring plots and/or incorporation of forest health monitoring of other disturbances in a subset of growth and yield plots. Part of a national network of plots to monitor changes in forest health resulting from climate change. (NL)
- Development of (national) monitoring protocols and their integration into existing growth and yield plots. (YT)
- Ability to inform economic impact assessments and improved suite of management options/ tools for forest managers/stakeholders. (NS)

ADAPTATION OPTION NO. 3: IDENTIFY ACCEPTABLE MONITORING LEVELS AND EFFICIENCIES

Outcomes of this adaptation will inform the first two adaptations. A key aspect is accounting for the uncertainty associated with climate change in the determination of the acceptable levels of FHM to ensure that climate-induced changes are being sufficiently captured (Adaptation Option No. 4). Once these levels have been determined, efficiencies can be sought to minimize FHM resource needs, which will undoubtedly be higher than current needs with the addition of a climate change component. Implementation of this adaptation will improve resilience of the FHM system as it will be based on minimizing vulnerability to climate change by incorporating uncertainties into monitoring regimes.

The majority of jurisdictions have reviewed their forest health program and identified efficiencies as part of their regular program reviews. Some have also identified opportunities for resource-sharing and collaborative efforts. Two jurisdictions indicated their minimum acceptable levels of FHM:

- Annual aerial overview surveys of one of five forest health zones, hence, a five-year rotational survey. (YT)
- Annual aerial overview surveys over entire province. (BC)

IMPLEMENTATION REQUIREMENTS

GOVERNANCE AND RESOURCE NEEDS

Changes to legislation, policies or regulation, or resource needs resulting from this adaptation will be addressed in the first two adaptation options.

RESOURCES AND SUPPORT

Support

Analytical and research support (Adaption Option No. 4) will be required, either internally or externally, depending on the jurisdiction.

OPERATIONS

Analysis and Planning

Monitoring priorities and regimes for the purposes of detecting climate-induced changes should be informed by science: analysis of different climate change scenarios and their potential effects on disturbance patterns. In essence, a more comprehensive and perhaps finer scale assessment than that undertaken for this national review is required. This will assist in determining the minimum levels of monitoring (e.g. frequency, intensity, distribution) required to sufficiently capture climate-induced damage while accounting for uncertainty. Initially, monitoring may have to increase to account for higher levels of uncertainty. If and when uncertainty associated with climate change is reduced, FHM could be relaxed or adjusted in consideration of new knowledge.

In terms of aerial surveys, it could help direct survey activities to areas/hosts that are more likely to incur climate-induced damage; for ground surveys, it could provide for a flexible or tiered sampling system with sampling efforts being proportional to uncertainty. In the absence of an uncertainty analysis, Natural Resources Canada's climate change adaptation website is a good resource for climate-related tools including Bioclimatic Mapping of Forest Insects and Diseases, which could be used to inform monitoring practices.

The planning aspect would involve identifying efficiencies by conducting an inventory of existing forest health monitoring personnel as well as prioritizing where and how to deploy them operationally. This aspect will be informed by the climate change monitoring priorities (with embedded uncertainty) defined above. Additionally, efficiencies should be sought through collaborative monitoring efforts or through investments in new technologies that fulfill multiple resources objectives. In the case of invasive species, this aspect should include collaboration and coordination with the CFIA to determine the best use of pooled resources.

- The CFIA already has a prioritization process for monitoring activities in terms of urgency and importance of the data to be gathered. The CFIA also has a number of partnerships in place. Any new information on how to use our resources appropriately would need to be incorporated in our planning processes and procedures. Monitoring protocols would also likely need to be revised. (CFIA)
- Our current system fits our needs; however, in the medium term, changes will need to be made to better track the effects of climate change. Initially monitoring will need to be increased (e.g. larger network of plots, to account for uncertainty); hence, more funding will be required. (QC)

- This initiative is not required in BC as an internal review process has already been undertaken, and minimum acceptable monitoring levels have been determined. (BC)

Procedures and Protocols

Procedures for quantifying and integrating uncertainty into monitoring practices will need to be developed by specialists, either internally or externally, depending upon the availability within each jurisdiction. These monitoring regimes should to be informed by science and evolve and adapt as knowledge of climate change uncertainties are identified or reduced.

SUCCESSFUL IMPLEMENTATION INDICATORS

The following were identified as indicators of successful implementation:

- Minimum acceptable levels of monitoring would be established and partnerships formed to determine how best to allocate resources. (AB)
- Baseline monitoring with expansions or exclusions based on new knowledge. (MB)
- Decision support tools (e.g., interactive maps) that will quantify uncertainty in forecasts on the fly and used to target extra sampling. (NB)
- A future monitoring network equivalent in size to the current network, but better adapted to follow the pest problems that will appear or that will persist with climate change. (QC)
- Identification and implementation of acceptable monitoring network to monitor all forest disturbances. (QC)
- Surveys delivered in partnerships to cover a larger area of the country and/or to target a wider variety of pests. Various tools (apps, etc.) are being used to maximize the likelihood of early detection and to manage pests. (CFIA)

ADAPTATION OPTION NO. 4: PROMOTE RESEARCH NEEDS AND MAINTAIN EXISTING RESEARCH CAPACITY

Research needs were identified by the CCFM in 2014[4], with spatial and temporal analysis of pest data to detect climate-related changes in pest patterns ranked as the number one research topic overall. This includes anticipated changes in secondary pest behavior, as these pests may displace the major pests or become more prolific in stressed forests. Climate change as a "pest" was ranked as the third most important forest disturbance, following eastern spruce budworm and mountain pine beetle. This supports the need for climate change research and maintenance of core competencies related to climate change. Research is required to improve our understanding of the potential impacts associated with forest disturbances and the relationships between biotic and abiotic factors and their hosts, as well as developing modelling tools ex. BioSIM, and techniques for decision-making and scenario-planning exercises. This includes tools such as remote sensing for FHM systems and assisting with developing monitoring regimes, which integrate climate change uncertainty.

Promotion of national and jurisdictional research needs has occurred through the aforementioned report, which is readily available on the CCFM website, as well as through various presentations and meetings since 2014.

[4] Hodge, J.C., 2014. Science and Technology: Forest pest research needs and priorities across Canada. Canadian Council of Forest Ministers, Forest Pest Working Group. Ottawa, Ontario. 78 p.

As the majority of jurisdictions have limited or no research capacity, their research needs are also promoted via external providers or facilitators. These include academia, CFS, TRIA-net (Turning Risk Into Action Network), SERG-I (Spray Efficacy Research Group – International), fRI (Foothills Research Institute), and the Forest Pest Working Group. Despite these efforts to promote research needs, some jurisdictions expressed concerns that they are not reaching the intended audience.

IMPLEMENTATION REQUIREMENTS

GOVERNANCE AND RESOURCE NEEDS

Changes to legislation, policies, or regulation as well as resource needs resulting from this adaptation will be addressed in the first two adaptation options.

Support

Internally, support from senior managers is generally required and support from the research community will be required externally. Shared research needs and opportunities for collaborative efforts should be identified and promoted as such.

- In BC where there is internal research funding, staff submit research proposals with research conducted either internally or externally.
- Jurisdictions support research initiatives which inform policy or decision-making via SERG-I, fRI, or as participating members of the CCFM FPWG and Technical Committee. Many of these are collaborative efforts and include in-kind contributions.
- The CFIA already has a process in place to identify, prioritize and promote research needs, and a research budget to allocate towards projects that help to address these needs. Research needs identification/prioritization processes could be changed as needed. A larger budget would also help address these needs in a timelier manner.

A few jurisdictions identified the need to have a more effective means of communicating research needs to the research community, and that the research community needs to be more receptive to operational needs. This includes consultation between the different levels of government and research institutions (universities, institutes, etc.) as to research needs, some of which would be relevant to FHM as it relates to climate change.

SUCCESSFUL IMPLEMENTATION INDICATORS

The following were identified as indicators of successful implementation:

- Research is successfully promoted, undertaken and delivered. This will provide for timely access to tools, methods and information to help achieve adaptation options including the following:
  - An increase in the number of research projects dealing with forest pest monitoring;
  - Maintenance of internal research capacity; and
  - Monitoring regimes and protocols which account for climate change uncertainties.
- Improved communication and better access to the research community.
- Improved consultation between different levels of government regarding research needs.
- Coordinated and collaborative efforts between jurisdictions/agencies promoting shared research needs.

COMMUNICATION

While raising awareness and understanding was not specifically identified as a priority adaptation option, this theme resonated throughout all of the responses. Every jurisdiction expressed a need to communicate with senior managers, decision makers, or other staff and departments about adaptation and the potential benefits and results of adaptation implementation. Communication was seen as essential to:

- Obtaining buy-in (internal and external) for support of for any new technologies;
- Justifying expenditures and/or redistribution of exiting personnel, particularly in the case of internal or external resource-sharing;
- Outlining the benefits of collaborative efforts;
- Providing rationale as to how adaptation options can complement existing systems or address monitoring gaps;
- Garnering support for the integration into existing monitoring methods;
- Raising awareness regarding the benefits of adaptation options to all stakeholders, including government;
- Sharing results with other governments or departments for decision-making purposes; and
- Highlighting the benefits of forest health monitoring to climate change adaptation in general.

One jurisdiction expressed that communication of key messages via the CCFM would provide leverage to support climate-related monitoring.

EVALUATION OF ADAPTATION PERFORMANCE

While indicators of successful implementation are outlined for each adaptation option, an overall evaluation of the FHM system is required. This involves assessing whether implementation has led to achievement of forest health monitoring objectives, and if not, what changes are required to do so. Table 5 outlines evaluation methods and tactics to enhance effectiveness of adaptation options if FHM objectives are not being achieved. In essence, this is a form of adaptive management and is key to improving the resilience and adaptive capacity of the FHM system. The "learn by doing" adaptive management approach will also help in reducing uncertainties and hence provide for efficiencies in FHM systems. Adopting an adaptive management approach is particularly important given that disturbance patterns are expected to change; hence, FHM practices will have to evolve or adapt accordingly.

Table 5. Potential approaches to evaluating monitoring practices, and tactics to enhance effectiveness, by forest health monitoring objective.

Forest Health Monitoring Objective	Evaluation	Tactics to Enhance Effectiveness
Detect and record biotic and abiotic disturbances to Canada's forest.	Determine: 1) if monitoring gaps (northern and remote) have been addressed, and if they are capturing a broader spectrum of pests and climate-induced damage or changes; 2) if monitoring practices are capturing climate change impacts; 3) if remote sensing interpretations are accurate by conducting ground checks for validation; more monitoring tools exist; 4) if staff/personnel are adequately trained.	Adjust aerial survey or remote sensing efforts to address gaps Relocate monitoring plots to ensure they capture geographic extent of disturbances Adjust remote sensing interpretations Review and adopt new technologies as warranted by cost/benefit analysis Adjust training and quality assurance/ quality control standards Promote more effective monitoring tools as a research need
Evaluate results to help improve understanding of hazard and risk.	Cross reference various monitoring methods to ensure that monitoring efforts are reflective of actual population levels. This will improve understanding of hazard, risk, treatment thresholds and management strategies.	Adjust monitoring protocols
Help inform forest health management decisions.	Determine: 1) if there are lower pest impacts due to proactive forest pest management practices; 2) if resource management strategies incorporate forest health; and 3) if policies are being influenced by forest health science.	Improve communications and knowledge transfer

Discussion and Summary

Climate change has already influenced disturbance patterns and modified HRVs in several jurisdictions. While this report characterizes some expected changes in disturbance patterns, there still remains much uncertainty as to when and where they will occur on the landscape, how they will interact, and how host tree species will respond to changing climate. This challenges the ability to capture changes given current forest health monitoring policies, practices and capacity, particularly since there are already monitoring gaps across Canada. The outcomes of this assessment have shown that existing FHM systems are vulnerable to climate-induced changes and that adaptation is required to ensure that disturbance patterns are adequately captured.

Vulnerability undoubtedly varies at a jurisdictional level given the differences in capacity and maturity of FHM programs. The NWT, for instance, has limited capacity and limited knowledge of baseline disturbance patterns against which to compare future disturbance patterns. This is concerning, given that northern latitudes are expected to be "the canaries in the coal mine" in terms of climate-induced changes. For example, drunken forests associated with permafrost melting will lead to significant areas of forest decline as 40% of the forested area of the boreal forest is permafrost.[5]

[5] Price, D.T, Alfaro, A.I., Brown, K.J., Flannigan, M.D., Fleming, R.A., Hogg, E.H., Giardin, M.P., Lausta, T. Johnston, M. McKenney, D.W., Pedlar, J.H. Stratton, T., Sturrock, R.N., Thompson, I.D. Trofymow, J.A., Venier, L.A.. 2013. Anticipating the consequences of climate change for Canada's boreal forest ecosystems. Environ. Rev. 21:322-365.

Without a robust FHM system, this decline may go undetected. This will have implications on a number of resource values, including boreal carbon reserves, and the potential for increased damage from both primary and secondary biotic agents.

One of the first steps to building adaptive capacity is increasing awareness that climate change will have an effect on disturbance patterns with resultant impacts to sustainable forest management. This awareness must occur at all levels of government, including senior managers and decision and policymakers, in order for adaptation actions to be considered and resourced. Although not explicitly identified as an adaptation priority, communication is as an integral first step. Communication messaging should be geared towards a culture shift from reactive to proactive management, one that incorporates biotic and abiotic disturbances across the forested landscape. This report should be viewed as a form of such communication.

The four priority adaptation options aim to build adaptive capacity and, in doing so, reduce FHM vulnerability to climate change. Adaptation will involve supplementing or complementing existing FHM systems with new technologies and broadening monitoring scope beyond managed forests and major pests. Monitoring regimes (e.g. frequency, intensity, resolution) will be informed by science, with the minimum acceptable level of monitoring developed with climate change uncertainties in mind. Maintenance of core climate change competencies within the research community is vital to adaptation, as is having the ability to promote and share research needs.

Implementation needs vary by adaptation option and by jurisdiction/agency and are dependent upon existing capacity, maturity of FHM program, and historical and current level and assemblage of forest disturbances. The use of remote sensing to supplement aerial surveys will require investments to acquire imagery and capacity to maintain and provide analytical support. Cost-sharing between departments could help minimize costs and fulfill multiple objectives. Expansion and modifications to monitoring regimes may provide an opportunity for harmonization of monitoring techniques across jurisdictions and collaborative efforts for interjurisdictional disturbances.

This vulnerability assessment validates concerns previously expressed by the forest health community regarding the ability to meet forest health monitoring objectives in light of climate change. In large part, this is due to uncertainty associated with climate change and institutional resistance to change in light of uncertainty, as well as limited capacity to conduct FHM activities in some jurisdictions, forest management policies, and the availability of efficacious and cost-effective monitoring tools. Implementation of the adaptations outlined in this report are meant to reduce FHM vulnerability and in doing so improve resiliency of the FHM system.

LESSONS LEARNED

A few lessons were learned during the course of this assessment. Firstly, the vulnerability assessment guidebook is geared towards sustainable forest management; hence the steps had to be adapted to assessing a human system rather than a biophysical system. Secondly, face to face meetings are a better means of gathering information than online surveys, as they allow for group discussions and clarification of the questions at hand. This was most apparent in the online responses regarding implementation, which would have undoubtedly benefited from group exercises or discussion. Thirdly, participants should have been encouraged to think beyond existing FHM limitations.

ANNEX I. *Participants*

PHASE 1 – 2016/2017	**PHASE 2 – 2017/2018**
October 2016 Workshop	Digital Surveys - Excel, Online
Erica Samis (AB)	Tim Ebata (BC)
Tom Hutchison (AB)	Harry Kope (BC)
Mike Undershultz (AB)	Rob Legare (YT)
Caroline Whitehouse (AB)	Jakub Olesinski (NWT)
Rory McIntosh (SK)	Tom Hutchsion (AB)
Jakub Olesinski (NWT)	Rory McIntosh (SK)
Rob Legare (YT)	Fiona Ross (MB)
Alvaro Duran (ON)	Maureen Kershaw (ON)
Maureen Kershaw (ON)	Pierre Therrien (QC)
Mike Jenkins (City of Edmonton)	Jeremy Gullison (NB)
Kelvin Hirsch (CFS)	Drew Carelton (NB)
Jason Edwards (CFS)	Celia Boone (NS)
David Price (CFS)	Dan Lavigne (NL)
Jean-Noel Candau (CFS)	Mireille Marcotte (CFIA)
Tod Ramsfield (CFS)	Anthony Hopkin (CFS)
Ted Hogg (CFS)	
Anthony Hopkin (CFS)	
Pierre Bilodeau (CFIA)	
Andrea Saunders (CFIA)	
Janice Hodge (NFPS)	
Rory McIntosh (SK)	
Tim Ebata (BC)	
Email	
Tim Ebata (BC)	
Kyla Maslaniec (MB)	
Pierre Therrien (QC)	
Jeremy Gullison (NB)	
Dustin Oikle (NS)	
Dan Lavigne (NL)	

ANNEX 2. *Existing Practices*

ADAPTATION OPTION NO. 1 – INTEGRATION OF NEW TECHNOLOGIES

Jurisdiction	Technology	Practice	Disturbance
AB	Remote Sensing	Automated processing MPB red/grey trees; assessing areas not regularly surveyed.	Mountain pine beetle
AB	DSS	To identify sties for treatment	Mountain pine beetle
AB, BC	Diagnostic Application		BC: Invasive weeds, other pest taxa (under development by ISC[1]
AB	Molecular Tools	Assess trees for disease resistance and drought tolerance	Western gall rust, white pine blister rust, drought
AB, NB, NS	Mobile Technology/ Software	AB: ESRI Collector, Survey 123 for monitoring, NB, NS: Data collection	All
SK	Aerial Photography	Preliminary work on change detection	Mountain pine beetle
	GIS Analysis	Help focus and prioritize monitoring activities	
ON	Remote Sensing	To augment forest health monitoring program – under development	All
QC	Molecular Diagnostics		Pathogens
NB	Mobile Technology	Streamlined data collection/compiling process	
NB	Unmanned Aerial Vehicle	Stand assessment of forest damage	

[1] Invasive Species Council of British Columbia

ADAPTATION OPTION NO. 2 - ADOPT PROACTIVE FOREST HEALTH MONITORING PRINCIPLES

Adaptation Option No.	Jurisdiction	Practices
2	BC, YT, NWT	Aerial overview surveys capture all biotic and abiotic disturbances
	AB, SK	Collaborative work with CFS on Climate Impacts on the Productivity and Health of Aspen (CIPHA) plots: CIPHA in collaboration with CFS
	AB	Mainstreaming forest health into long and short-term forest management plans Increased external monitoring capacity and coverage via training of forest industry to recognize forest pests and understand their potential impact Extended aerial overview surveys to collect spatial information on a wider range of forest damage agents; more emphasis placed on ground-truthing
	BC	Young Stand Monitoring (YSM) plots are being used as forest health monitoring plots Drought working group looking at utility of establishing network of drought monitoring plots with the forest research group
	SK	Ground assessments (every two years) of areas with wind disturbance to better understand the short and long-term risks to standing healthy forests associated with insect populations infesting wind throw
	MB	Some forest health information is currently collect by growth and yield plots
	QC	PSPs established since 2001 to monitor insects and diseases; located in the same stands as the Forest Inventory Branch PSPs. Also, semi-permanent plots are established once a pest is discovered and maintained until the population collapses; temporary sample plots are established for shorter-term needs

ADAPTATION OPTION NO. 3 – IDENTIFY ACCEPTABLE MONITORING LEVELS AND EFFICIENCIES

Adaptation Option No.	Jurisdiction	Practices
3	AB	Use of aerial overview surveys to guide more expensive and detailed heli-GPS surveys Expanded usage of aerial overview surveys due to lower relative costs Collaboration with other departments/program areas to reduce costs i.e. using unused helicopter time from the wildfire program, provincial park and wildfire staff participate in MPB survey/control programs Participation in the NFPS diagnostic and operational program expertise
	NWT	Current monitoring system addressed known limitations
	MB	More intensive monitoring initiated as pest problems arise
	SK	Exploring the feasibility of streamlining risk-based forest health surveillance, monitoring, and response throughout all forested landscapes
	ON	IMF plan and collaboration with different sections (growth and yield, forest inventory, forest science, etc.)
	QC	Work in progress, as many of our decisions are dependent on the actions that managers will take to adapt the forest of QC to climate change; the work has begun and we have had discussions with them, but nothing is finalized
	NS	Some sampling protocols provide for monitoring multiple pests during a field trip

ADAPTATION OPTION NO. 4 – PROMOTE RESEARCH NEEDS AND MAINTAIN EXISTING CAPACITY

Adaptation Option No.	Jurisdiction	Practices
4	All except CFIA	Promote or support research needs which inform forest health policy or decision making via one or several of the following: SERG-I, fRI, NSERC-TRIA Net, Saskatchewan Research Council (SK only) and NFPS FPWG
	SK	Supports a PhD student working on vulnerability assessment and adaptation framework within an industrial setting

ANNEX 3. *Responsibilities*

ADAPTATION OPTION NO. 1 – INTEGRATION OF NEW TECHNOLOGIES

Jurisdiction	Responsibility
British Columbia	Forest Health Program of MFLNRO Resource Practices Branch
Alberta	Forest Health and Adaptation
Yukon	Director of Forest Management Branch, Energy, Mines and Resources
Northwest Territories	Uncertain
Saskatchewan	Forest Inventory Branch, Ministry of Environment – Remote Sensing
	Communication Branch, Ministry of Environment – App Development
Manitoba	Manitoba Sustainable Development – Forestry and Peatlands Branch
Ontario	Regional Operations Division and Biodiversity and Monitoring, Ministry of Natural Resources and Forestry
Quebec	Forest Pest Management Service of the Ministère des Forêts, de la Faune et des Parcs du Québec
New Brunswick	Manager of Forest Planning and Health, Ministry of Energy and Resource Development
Nova Scotia	Risk Services Branch, Dept. of Natural Resources – development, protocols Forest Health, Dept. of Natural Resources – implementation
Newfoundland	Newfoundland Department of Fisheries and Land Resources (DFLR) Insect and Disease Control Section and DFLR GIS and Mapping Division
CFIA	Science Branch, and Policy and Programs Branch

ADAPTATION OPTION NO. 2 – ADOPT PROACTIVE FOREST HEALTH MONITORING PRINCIPLES

Jurisdiction	Responsibility
British Columbia	MFLNRO Resource Practices Branch FH specialists, silviculturalists, industry, etc.; this is a multi-stakeholder activity
Alberta	Internally, FH&A would play a lead role with cooperation from other departmental staff and other ministries; externally, FH&A would again take a lead role, especially for providing extension services to industry and other partners
Yukon	Uncertain
Northwest Territories	Uncertain
Saskatchewan	Saskatchewan Ministry of Environment Forest Service Branch would lead with collaboration from other ministries
Manitoba	Manitoba Sustainable Development – Forestry and Peatlands Branch
Ontario	Will be determined by the integrated monitoring team – Regional Operations Division and Biodiversity and Monitoring, Ministry of Natural Resources and Forestry
Quebec	Forest Pest Management Service of the Ministère des Forêts, de la Faune et des Parcs du Québec

Jurisdiction	Responsibility
New Brunswick	Renewable Resources Inventory Manager, Ministry of Energy and Resource Development
Nova Scotia	Forest Health (implementation), Risk Services (development, protocols), Forest Inventory, Forest Resource Management. Dept. of Natural Resources; pest detection officers may be used in various regions
Newfoundland	National Forest Pest Strategy Newfoundland Department of Fisheries and Land Resources (DFLR) Ecosystem Management Division – Forest Inventory Section, DFLR Forest Insect & Disease Control Section

ADAPTATION OPTION NO. 3 – IDENTIFY ACCEPTABLE MONITORING LEVELS AND EFFICIENCIES

Jurisdiction	Responsibility
British Columbia	Forest Health Program of MFLNRO Resource Practices Branch
Alberta	Internally Forest Health and Adaptation (FH&A) would play a lead role with cooperation from other departmental staff and other ministries; externally, FH&A would again take a lead role, especially for providing extension services to industry and other partners
Yukon	Director of Forest Management Branch, Energy, Mines and Resources
Northwest Territories	Uncertain
Saskatchewan	Saskatchewan Ministry of Environment Forest Service Branch would lead with collaboration from other ministries
Manitoba	Manitoba Sustainable Development – Forestry and Peatlands Branch
Ontario	Regional Operations Division and Biodiversity and Monitoring, Ministry of Natural Resources and Forestry
Quebec	Forest Pest Management Service of the Ministère des Forêts, de la Faune et des Parcs du Québec
New Brunswick	Manager of Forest Planning and Health, Director of Forest Planning and Stewardship, Ministry of Energy and Resource Development
Nova Scotia	Forest Health (implementation), Risk Services (development, protocols), Forest Inventory, Forest Resource Management. Dept. of Natural Resources; pest detection officers may be used in various regions
Newfoundland	Newfoundland Department of Fisheries and Land Resources (DFLR) Insect and Disease Control Section
CFIA	It would be up to each organization to include the information in their decision-making processes.

ADAPTATION OPTION NO. 4 – PROMOTE RESEARCH NEEDS AND MAINTAIN EXISTING CAPACITY

Jurisdiction	**Responsibility**
British Columbia	FH specialists who receive funding through the FLNRO Intended Outcomes research process
Alberta	Forest Health and Adaptation would play a lead role with cooperation from other departments and ministries as well as other interested stakeholders
Yukon	Uncertain
Northwest Territories	Uncertain
Saskatchewan	Saskatchewan Ministry of Environment Forest Service Branch would lead with collaboration from other ministries and stakeholders, as appropriate
Manitoba	Forestry and Peatlands outline research gaps and look at partnership opportunities to help fill these information gaps
Ontario	Senior Management of Ministry of Natural Resources and Forestry
Quebec	Under the direction of research branch of the Ministère des Forêts, de la Faune et des Parcs du Québec and the Forest Pest Management (for pest detection research needs)
New Brunswick	Manager of Forest Planning and Health, Ministry of Energy and Resource Development
Nova Scotia	Forest Health (implementation), Risk Services (development, protocols), Forest Inventory, Forest Resource Management. Dept. of Natural Resources Dept. of Natural Resources; pest detection officers may be used in various regions
Newfoundland	Group exists within the DFLR already dedicated to forest and wildlife management R&D
CFIA	The Plant Research and Strategies Unit in the Plant Health Science Directorate at the CFIA is responsible for the CFIA Processes and could work with those responsible in other organizations to harmonize as needed/if possible