

INDICATOR EVALUATIONS

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INDICATOR EVALUATIONS

INDICATOR 1.1.1 *AREA OF FOREST, BY TYPE AND AGE CLASS, AND WETLANDS IN EACH ECOZONE*

1. Linkages Assessment

Table 1.1. Indicators influencing Indicator 1.1.1.

Indicator 1.1.1	Influencing Indicators
First order positive	2.5
First order negative	None
First order bi-directional	1.2.2, 1.2.3, 1.2.4, 2.2, 2.3, 2.4, 3.3, 5.3.1, and 5.3.2

Table 1.2. Indicators influenced by Indicator 1.1.1.

Indicator 1.1.1	Influenced Indicators
First order positive	None
First order negative	None
First order bi-directional	1.2.1, 1.2.2, 1.2.3, 2.1, 2.3, 3.3, 4.1.1, 4.1.2, 5.1.5, 5.2.1, 5.3.1, and 5.3.2

- 1.1. Which indicators are influencing and influenced directly (first-order interactions) by the indicator in question? Is the indicator more of a driver of change in other indicators, or being driven by other indicators?

Indicator 1.1.1 is influenced by 10 other indicators, primarily from Criteria 1 and 2. Notable exceptions include Indicators 3.3, 5.3.2, and 5.3.2. It influences 12 other indicators directly, many of which were also found to influence it. As a biophysical descriptor of Canada's forests, this Indicator is both a major driver for all components of SFM, but also highly influenced by many different human activities, ecological processes, and global biogeophysical cycles.

- 1.2. List the indicators described as 'relevant indicators under other criteria' in the 2003 C&I-SFM. Is there any conflict with the interactions described in the matrix?

The 2003 C&I framework describes two important determinants of forest-ecosystem diversity. Firstly, Indicator 2.2 provides insight into changes in ecosystem diversity, and what the drivers of that change are. Secondly, the distribution of forest-types and age-classes is highly dependent on natural and anthropogenic disturbance levels, as signalled by Indicator 2.3.

- 1.3. Are there any overlaps or gaps in the relationship with indicators defined in Eddington and colleague's (2009) report?

The FFEI Indicator 12 *Ecosystem Distribution and Composition* is closely allied to Indicator 1.1.1, but focuses primarily on British Columbia's Biogeoclimatic Ecosystem Classification for the scale of assessment. Ecosystem diversity is described by Eddington and colleagues (2009) as a critical component of monitoring forests and rangeland in the face of climate change, because the changes in 'climate envelopes', or climatic ranges of tree species, will likely lead to considerable alterations to forest-community assemblages and distributions.

2. Independent Climate-Change Assessment

- 2.1. Provide in detail, a qualitative description of what are the expected direct effects of climate change on the indicator, using a broad representation from the literature.

Climate change will more than likely have a profound effect on forest-ecosystem diversity in Canada. For the sake of clarity, it is useful to separate forest area, type, and age from the area of wetlands as we consider climate change. The type of forest, in terms of forest composition, is expected to sustain considerable change over the next century, due primarily to climate-driven changes in tree species distributions (McKenney et al., 2007; Iverson et al., 2008). Many national- and continental-scale modelling initiatives have simulated changes in North American tree-species distributions using a wide array of GCMs and IPCC scenarios. The general consensus is a northward and upward shift in the range of tree species due largely to the warming temperature.

The area of forest in Canada may be affected by climate change on both climatic extremes. The advance of treelines at high altitudes and latitudes is a widely speculated impact (Aitken et al., 2008; Williamson et al., 2009). Conversely, in warmer climes where forests are limited by moisture, such as in the western Canadian interior, a decline in growing-season precipitation is expected to cause widespread dieback of the aspen parklands forest (Hogg et al., 2008). The age-class distribution of forest ecosystems is not as vulnerable to the direct influence of climate change (Steenberg et al., 2010). However, indirect climate-change effects by way of altered natural disturbance regimes will have drastic implications for forest age-class distribution (Dale et al., 2001).

Wetlands occupy the transitional zones between aquatic and terrestrial ecosystems and are very sensitive to changes in their water-supply quantity and quality, making them vulnerable to climate change (Hulme, 2005; Erwin, 2009). Changes in hydrology, biogeochemistry, and biomass-accumulation patterns of terrestrial ecosystems due to increased temperatures and precipitation levels may severely impact the function of wetlands, including the area of wetlands in Canada's terrestrial ecozones (Burkett & Kusler, 2000). Furthermore, sea-level rise is described as a serious threat to coastal wetlands (IPCC, 2007).

- 2.2. Given expected changes in Canada's climate, describe if and how the indicator's ability to signal progress towards SFM remains unchanged.

The ability of Indicator 1.1.1 to signal our progress towards SFM will not remain the same under climate change.

- 2.3. If an indicator's ability to signal progress towards SFM will be changed, describe if and how the indicator may become worse or better at signalling SFM progress.

Indicator 1.1.1 is a highly diverse and encompassing indicator, and it will likely be among the indicators most affected by climate change within the C&I framework. It tracks physical forest-ecosystem conditions within Canada and its terrestrial ecozones, which is arguably one of the most fundamental and important pieces of information pertaining to biological diversity (CCFM, 2006). This is because it sheds light on the extent, type, and diversity of different forest habitats, which is influential on all ecosystem components, including species and genetic diversity, and their management. The potential for wetland area and forest type, area, and age to be affected by climate change is high, which implies a considerable decline in the predictability, responsiveness, and relevance of Indicator 1.1.1. A considerable challenge will be discerning what changes in forest-ecosystem diversity can be attributed to forest management activities and what can be attributed to the changing climate.

3. Integrated Climate-Change Assessment

- 3.1. What are the key determinants of the indicator (i.e. what causes it to change when it does change);

- a) Among other indicators in the C&I framework?
 - **The extent and intensity of forest disturbance is a key determinant of forest age and type. Stand-replacing disturbances such as fire, severe blowdowns, and timber harvest drastically alter forest age-class distributions (Frelich, 2002). Also, the frequency and intensity of disturbance strongly influences forest composition, such as stand-maintaining surface fires that favour forests composed of fire-tolerant species (Oliver & Larson, 1996). Therefore, Indicators 2.3, 3.3, and 1.2.4 are key determinants of Indicator 1.1.1.**
 - **Indicators 2.2 and 2.5 are key determinants of the area and age of forest ecosystems.**
 - **Human influence on forest ecosystems in the form of forest management also has a large influence on diversity. As such, Indicators 5.3.1 and 5.3.2 are determinants of Indicator 1.1.1.**
 - **Indicator 3.3 has important implications for wetland dynamics within a watershed.**

- **One of the primary goals in the assessments of Indicator 1.1.1 is to get a sense of forest-habitat quantity and quality. However, forest-associated species also affect the habitat they dwell in through competition and browsing. Thus, Indicators 1.2.2 and 1.2.3 are determinants of Indicator 1.1.1.**

b) Among determinants not within the C&I framework?

- **Climate is a major determinant of species and community distribution, and as such is a key determinant for the diversity of forest types.**
- **Site conditions, such as soil-nutrient and moisture regimes, geology, slope, drainage, and aspect are all influential on forest ecosystem diversity and wetlands.**
- **The hydrological processes of watersheds are a key determinant of wetlands, as are human impacts within watersheds, such as hydro-electric dams that are a major contributor to wetland loss.**

3.2. For what other entities is this indicator a key determinant (i.e. when it changes, what other indicators are influenced to change);

a) Among other indicators in the C&I framework?

- **Indicator 1.1.1 is an indicator of forest habitat and its diversity, and as such it is a key determinant of forest-associated species, tracked by Indicators 1.2.2 and 1.2.3.**
- **The area, type, and most importantly, age of forests are a major determinant of the growing stock of trees and of ecosystem carbon. This links Indicator 1.1.1 to Indicators 2.1, 4.1.1, and 4.1.2.**

b) Among determinants not within the C&I framework?

- **Wetlands are an important determinant of water quality, quantity, and indeed the health of a watershed, including all the species that are dependent on wetlands in some or all of their life-cycles.**
- **As Indicator 1.1.1 signals a coarse portrayal of the entirety of Canada's forests, it is a determinant for nearly all ecological processes, forest-derived social and economic services, and Canada's role in global-carbon and hydrological cycles, both within and external to the C&I framework.**

3.3. To what degree can we now, on the basis of extant knowledge, establish how the key determinants interact cumulatively in influencing the indicator?

The dynamics and drivers of forest-ecosystem diversity are well researched and we often have a reasonable grasp of the cumulative influence of forest-ecosystem processes and the sphere of human influence. Climate and site conditions are both determinants of forest vulnerability to natural disturbances that may interact cumulatively. An relevant example is concurrence of dry growing seasons in areas with moisture-limited soils that will increase the vulnerability of the forest to fire and other forms of disturbance, which in turn cumulatively alter forest age and type.

Wetlands are highly vulnerable to changes in water quantity and quality, and as such are frequently stressed or lost due to the combination of many stressors associated with anthropogenic land-uses. The cumulative effects of nutrient run-off from agricultural land, loss of storm-water retention due to development, and disruption of ground flow due to road construction may not individually lead to severe wetland decline, but combined may surpass a threshold of stress.

- 3.4. Is the indicator largely unrelated to any other, as described by the linkages assessment and evaluation of key determinants? If so, and the indicator was defined as uninfluenced by climate change in the independent assessment, then it can be placed in category one.

Indicator 1.1.1 is one of the most interrelated indicators within the C&I framework and to external determinants of change. Additionally, the entities that it monitors were found to be highly vulnerable to climate change, so we do not recommend assignment to category one.

- 3.5. Do the indirect effects of climate change via the linkages with other indicators influence the indicator's ability to signal SFM, regardless of which category was assigned in the independent climate-change assessment?

The primary source of indirect climate-change influence on Indicator 1.1.1 will likely be via changes in natural disturbance regimes. More frequent and severe forest fires, extreme weather events, and insect and disease outbreaks are all predicted impacts of climate change on forest ecosystems (Dale et al., 2001; Williamson et al., 2009). Furthermore, the number of invasive, alien species is predicted to increase with climate change (Dukes et al., 2009).

- 3.6. If the indicator's ability to signal SFM progress remains the same under a changing climate, can we conclude no negative influence and leave it unchanged? These indicators can be placed in category two.

Indicator 1.1.1 will suffer a decline in predictability, responsiveness, and relevance because of climate change. However, we see no possible modifications that could mitigate the deterioration of these indicator traits. Conversely, we suspect that there will be no major

decline in the SFM signal generated by Indicator 1.1.1. This is due to the fact that it is so interconnected with other indicators in the C&I framework and is influenced by so many biophysical and socioeconomic determinants, that modifications to other indicators in the framework and the creation of new indicators relating to climate change will suffice in maintaining the Indicator's ability to track SFM progress. We therefore recommend assigning it to category two, *Unmodified Indicators*.

- 3.7. If the indicator's ability to signal SFM progress deteriorates when one assumes a changing climate, then what modifications are possible or warranted to improve its ability sufficiently for it to remain among the C&I-SFM? These indicators can be placed in category three.

Not applicable.

- 3.8. If no modifications seem possible or warranted, are we ready to recommend abandonment of the indicator? These indicators can be placed in category four.

Not applicable.

- 3.9. If we recommend abandonment, can we identify any new and closely allied indicators that might suit our needs better under climate change? These indicators can be placed in category five.

Not applicable. There are no additional indicators that we recommend to monitor ecosystem diversity and its role in SFM in Canada.

- 3.10. Have extant climate-change impacts made this indicator more pertinent to SFM (i.e. 2.3 and the mountain pine beetle)? These indicators can be placed in category five or considered for conversion from a supporting to a core indicator (where applicable).

Canada's northern regions are predicted to be among the most vulnerable to climatic change, a prediction that has already been partially confirmed by longer growing seasons and earlier spring thaws (Goetz et al., 2005). Additionally, the transitional areas between major biomes or forest regions, called ecotones, are highly sensitive to climatic variation (Nielson, 1993). The treeline is comprised of young or stunted boreal trees, the delineation of which is limited primarily by temperature (Grace et al., 2002), and is a prime example of an ecotone in the Canadian north and at high elevations. Higher stand densities and treeline migration have already been observed in these regions and are attributed to the observed changes in climate (Danby & Hik, 2007).

Conversely, climatic change in warmer, southerly regions that are limited by moisture, such as the western Canadian interior's aspen parkland, have seen widespread mortality

and dieback of aspen (Hogg et al., 2008). Dieback has also been seen in the Atlantic Maritime ecozone, and was ascribed to more frequent spring thaw-freeze events (Bourque et al., 2005). Both of these differing climate-change impacts have led to changes in Canada's forest area, as tracked by Indicator 1.1.1.

3.11. How should the surviving indicator (the original, modified, or new) be modelled and monitored so that stronger SFM signals may be generated?

The data source for Indicator 1.1.1 is Canada's Forest Inventory (CanFI), which is a compilation of existing inventories from Canada's provincial and territorial jurisdictions that has been assessed multiple times, with the most recent being 2001 (CanFI, 2001; CCFM, 2006). Canada's National Forest Inventory, managed by the CFS and CCFM, is still actively monitoring forest conditions throughout the country, and will hopefully continue to be a primary data source for the measurement of ecosystem diversity. The baseline wetland area provided in the 2005 C&I-SFM status report (CCFM, 2006) is also sourced from the National Forest Inventory (CanFI, 2001). They are described as a benchmark for further analysis of wetland area in Canada for future assessment.

Furthermore, given the sheer extent of Indicator 1.1.1, there may be considerable utility in drawing from forecast modelling and remote-sensing tools in monitoring the Indicator. Remote sensing using satellite imagery provides an opportunity for monitoring changes in forest area and a coarse measure of cover-type over very broad spatial scales. Forecast modelling is a critical tool in climate prediction and subsequent analyses of forest-ecosystem responses that helps us devise management tools for uncertain future conditions, and is described as requirement of SFM (CSA, 1996).

3.12. Does this indicator track an entity whose relationship with climate is regionally variable?

The effects of climate change on Indicator 1.1.1 will be extremely variable between regions and will likely necessitate different approaches to modelling and monitoring to Indicator.

**INDICATOR 1.1.2 AREA OF FOREST, BY TYPE AND AGE CLASS,
WETLANDS, SOIL TYPES, AND GEOMORPHOLOGICAL FEATURE TYPES
IN PROTECTED AREAS IN EACH ECOZONE**

1. Linkages Assessment

Table 1.1. Indicators influencing Indicator 1.1.2.

Indicator 1.1.2	Influencing Indicators
First order positive	1.3.2
First order negative	None
First order bi-directional	1.2.2, 1.2.3, 1.2.4, 2.3, 2.4, and 3.3

Table 1.2. Indicators influenced by Indicator 1.1.2.

Indicator 1.1.2	Influenced Indicators
First order positive	1.3.2
First order negative	None
First order bi-directional	1.2.1, 1.2.2, 1.2.3, 2.1, 2.3, 3.3, 4.1.1, 4.1.2, and 5.1.5

- 1.1. Which indicators are influencing and influenced directly (first-order interactions) by the indicator in question? Is the indicator more of a driver of change in other indicators, or being driven by other indicators?

Indicator 1.1.2 is directly influenced by seven indicators, primarily from Criterion 1 and Element 1.2 within. It influences 10 other indicators, the majority of which also influence it. One exception is Indicator 5.1.5, as protected areas in Ontario were the subject of case studies in the 2005 C&I-SFM assessment (CCFM, 2006). Indicator 1.1.2 is both a driver of change and driven to change by other indicators within the C&I framework. This is concurrent with the findings in the interaction matrix.

- 1.2. List the indicators described as ‘relevant indicators under other criteria’ in the 2003 C&I-SFM. Is there any conflict with the interactions described in the matrix?

Many of the interactions with other indicators will be closely matched to those described in the evaluation of Indicator 1.1.1. The 2003 C&I framework describes two important determinants of forest-ecosystem diversity. Indicator 2.2 gives insight into drivers of change for forest-ecosystem diversity within protected areas. Also, the distribution of forest types and ages-classes is highly related to disturbance regimes within forest ecosystem, as signalled by Indicator 2.3. Tracking the soil types within protected areas is also deemed relevant to the conservation of soil and water resources, and therefore relevant to Criterion 3. Protected areas are highly influential on recreational values, as well as several other forest-based services, tracked by Indicator 5.1.5.

- 1.3. Are there any overlaps or gaps in the relationship with indicators defined in Eddington and colleague's (2009) report?

The FFEI Indicator 12 *Ecosystem Distribution and Composition* is very similar to Indicator 1.1.1, and is therefore closely related to Indicator 1.1.2. The key difference being that the FFEI indicators target only biophysical entities for monitoring, and therefore do not represent the connection of protected areas to socioeconomic benefits from forest-based services.

2. Independent Climate-Change Assessment

- 2.1. Provide in detail, a qualitative description of what are the expected direct effects of climate change on the indicator, using a broad representation from the literature.

For a detailed description of the climate-change effects on forest area, age, and type, and wetlands please see the evaluation of Indicator 1.1.1. The focus here is on the implications of climate change for forest ecosystems that are constrained by protected areas. Protected areas are amongst the most prevalent strategies for the conservation of biodiversity in Canada (Woodley & Forbes, 1995). It is safe to say that the total area of land that is protected within Canada is free from direct climate-change influence. However, the protected ecosystems within are afforded no such stability. In fact, because protected areas are most often spatially static, they have a fundamental failing in the face of global environmental change (Duinker, 1993).

Protected areas are usually designed to encapsulate enduring physical and ecological features *in situ* and in perpetuity, most often using a strategy similar to Parks Canada's natural-region representation approach to protected areas system planning, with the aid of jurisdictional land-classification frameworks (Scott & Lemieux, 2005). This strategy has a strong reliance on the assumption of biogeographic stability, which is invalidated by the predicted and extant changes in climate and forests in Canada. Climate change may also require that we redefine what we consider native due to the potential migration of species from the United States and between native forest regions (McKenney et al., 2007). Protected areas are therefore highly vulnerable to climate-driven, forest-ecosystem change, and to a subsequent loss of their associated biodiversity-conservation value (Lemieux & Scott, 2005; Scott & Lemieux, 2005). Scott and Lemieux dictate that "protected area system planners will be charged with protecting a moving target of ecological representativeness" (Scott & Lemieux, 2005, p. 698). While there is some research on potential economic benefits of climate change due to increased nature-based tourism in national parks driven by longer favourable seasons for tourism (Scott, 2003), the general consensus is that protected-areas planning will have to address climate change in order to have continuing value in biological-diversity conservation.

- 2.2. Given expected changes in Canada's climate, describe if and how the indicator's ability to signal progress towards SFM remains unchanged.

The majority of the variables that are assessed within Indicator 1.1.2 are expected to host an array of climate-change impacts, suggesting that this Indicator will not be unaffected in the future. The function of Indicator 1.1.2 in signalling progress towards SFM is to yield insight into our ability to protect representative forest areas (CCFM, 2006). This function is indeed compromised by climate change, due to the core assumption of biogeographic stability in protected areas system planning. Thus, ability of Indicator 1.1.2 to signal progress towards SFM will be changed.

2.3. If an indicator's ability to signal progress towards SFM will be changed, describe if and how the indicator may become worse or better at signalling SFM progress.

The ability of Indicator 1.1.2 to signal SFM progress will be diminished. Protected areas as a tool for the conservation of ecosystem diversity, and indeed biological diversity, are compromised by expected and experienced climate-driven changes in forest type, area, and age. This presents major impedances for the predictability, responsiveness, and relevance of the Indicator.

The challenges presented to protected areas managers in Canada by climate change and potential adaptation strategies are a complex and evolving issue that is well beyond the scope of this evaluation. Nevertheless, the question remains, can Indicator 1.1.2 still adequately track the role of protected areas in the conservation of biological diversity and in SFM? The issue at hand is that the current strategy of protected areas planning, policy, and management is not sufficient to maintain ecosystem diversity in a changing climate. However, protected-area strategies that incorporate climate-change adaptations, such as the selection of protected areas on ecotones and improving protected-area connectivity (Scott & Lemieux, 2005), may be able to adequately maintain ecosystem diversity and meet conservation objectives. Therefore, while climate change may diminish the ability of Indicator 1.1.2 to signal SFM progress under the current protected areas paradigm, it may still have utility as an indicator, unchanged, if protected area planning incorporates climate change.

3. Integrated Climate-Change Assessment

3.1. What are the key determinants of the indicator (i.e. what causes it to change when it does change);

- a) Among other indicators in the C&I framework?
- **Natural disturbances are a key determinant of the forests within protected areas. Stand-replacing disturbances from fires, severe blowdowns, and insect/disease outbreaks have great influence over forest age-class distribution (Frelich, 2002). Disturbance frequency and intensity also strongly influence forest composition. Therefore, Indicators 2.3, 3.3, and 1.2.4 are key determinants of Indicator 1.1.2.**

- **Indicator 3.3 is tied to the health and dynamics of watersheds, and as such is a determinant of wetland area.**
- **Indicator 1.1.2 is an indicator of habitat quality and quantity within protected areas. However, forest-associated species also influence their habitat through competition and browsing, making Indicators 1.2.2 and 1.2.3 determinants of Indicator 1.1.2.**

b) Among determinants not within the C&I framework?

- **Protected area planning, policy, and management in Canada, administered by Parks Canada, various territorial and provincial departments and ministries, and municipal governing bodies, are all key determinants for Indicator 1.1.2.**
- **A determinant for ecosystem diversity in protected areas is stress arising from recreational over-use.**
- **Climate is a key determinant of tree-species and ecosystem distribution in Canada's terrestrial ecozones, and is therefore highly influential on the diversity of forest types.**
- **Site conditions are a major determinant of the extent and type of forest ecosystems and of wetlands. These include soil-nutrient and moisture regimes, geology, slope, drainage, and aspect.**
- **Wetlands are highly sensitive to any changes in the flow or quality of water, making any changes to these attributes determinants of Indicator 1.1.2.**
- **Slow acting, geological processes are the determinants of many ecologically important and aesthetically pleasing geomorphological features within protected areas.**

3.2. For what other entities is this indicator a key determinant (i.e. when it changes, what other indicators are influenced to change);

a) Among other indicators in the C&I framework?

- **Indicator 1.1.2 is a major determinant of Indicator 5.1.5, due to the high recreational value of many protected areas, such as Ontario's Living Legacy Signature Sites used in the 2005 C&I-SFM assessment (CCFM, 2006).**

- **Indicator 1.1.2 is an indicator of forest habitat and its diversity in protected areas, and as such it is a key determinant of forest-associated species, tracked by Indicators 1.2.2 and 1.2.3.**
- **Protected areas are closely associated with *in situ* conservation efforts of native tree species, and thus Indicator 1.1.2 is a determinant of Indicator 1.3.2.**
- **The area, type, and most importantly, age of forests are major determinants of the growing stock of trees and of ecosystem carbon within protected areas. Thus, Indicator 1.1.2 is a determinant of Indicators 2.1, 4.1.1, and 4.1.2.**

b) Among determinants not within the C&I framework?

- **Wetlands are key determinants of water quality, quantity, and the health of a watershed, and are important habitat components for many species that are dependent upon them in some or all of their life-cycles.**
- **Protected areas are an integral component of biodiversity conservation. There is a myriad of ecological, economic, and social benefits that are in part determined by protected areas and the biological and geophysical components they protect.**

3.3. To what degree can we now, on the basis of extant knowledge, establish how the key determinants interact cumulatively in influencing the indicator?

Environmental impacts are frequently caused by human activities, many of which have only minor effects. Yet the cumulative interaction of these past, present, and future activities can have major environmental consequences (Beanlands et al., 1986). For example, the cumulative effects from nutrient run-off from agricultural land, loss of storm-water retention due to development, disruption of ground flow due to road construction, and wetland loss from development, urbanization, and agriculture, have led to significant losses in wetland area, unequal losses of wetland types, and declines in the integrity of remaining wetlands (Bedford, 1999).

The cumulative effects of forest management activities since European settlement, such as timber harvesting, fire suppression, road construction, and recreational activities, have altered the natural disturbance regimes and the forests of North America (Baker, 1992; McGarigal et al., 2001).

3.4. Is the indicator largely unrelated to any other, as described by the linkages assessment and evaluation of key determinants? If so, and the indicator was defined as uninfluenced by climate change in the independent assessment, then it can be placed in category one.

Indicator 1.1.2 is related to other indicators in the C&I framework and to external determinants of change. It was also found to be affected by climate change in the independent assessment, so we do not recommend assignment to category one.

- 3.5. Do the indirect effects of climate change via the linkages with other indicators influence the indicator's ability to signal SFM, regardless of which category was assigned in the independent climate-change assessment?

Indicator 1.1.2 will likely be affected by climate change directly, through the climate-driven changes in species distributions, as well as indirectly, via changes in natural disturbance regimes. An increase in the frequency and magnitude forest fires, extreme weather events, and forest insect and disease outbreaks are all predicted impacts of climate change on forest ecosystems (Dale et al., 2001; Williamson et al., 2009).

- 3.6. If the indicator's ability to signal SFM progress remains the same under a changing climate, can we conclude no negative influence and leave it unchanged? These indicators can be placed in category two.

The ability of Indicator 1.1.2 to signal SFM progress will be diminished by the predicted changes in climate. However, given the future potential of this indicator in signalling SFM described in the previous section, we recommend leaving it unchanged. This Indicator can therefore remain unmodified and be placed in category two, *Unmodified Indicators*.

- 3.7. If the indicator's ability to signal SFM progress deteriorates when one assumes a changing climate, then what modifications are possible or warranted to improve its ability sufficiently for it to remain among the C&I-SFM? These indicators can be placed in category three.

No modifications to Indicator 1.1.2 seem feasible to address the challenges presented by climate change to protected areas.

- 3.8. If no modifications seem possible or warranted, are we ready to recommend abandonment of the indicator? These indicators can be placed in category four.

We do not recommend indicator abandonment, as there is potential for Indicator 1.1.2 to regain its full utility in the near future and to partially signal the progress of protected areas planning, policy, and management to climate-change adaptation.

- 3.9. If we recommend abandonment, can we identify any new and closely allied indicators that might suit our needs better under climate change? These indicators can be placed in category five.

The ability of Indicator 1.1.2 to adequately track the role of protected areas in the conservation of biological diversity and SFM is reliant upon the incorporation of climate change into protected areas planning and policy. It may therefore prove helpful to track our progress towards this goal with a new indicator.

The International Union for Conservation of Nature (IUCN) has several major recommendations for maintaining the effectiveness of protected areas in conserving biological diversity in the face of climate change. The first is to “complete fully representative protected areas networks”, which can be sufficiently monitored by the current design of Indicator 1.1.2 (Dudley et al., 2010, p. 92). The second is to “promote connectivity”, which will be a critical element of protected areas as climate change drives the migration species and ecosystems (Dudley et al., 92). Connectivity is also widely recognized in the literature as being highly important for protected areas effectiveness in a changing climate (Scott & Lemieux, 2005; Hannah et al., 2007). We recommend *Connectivity of Protected Areas* as an additional indicator pertaining to the role of protected areas in biodiversity conservation and SFM. Also, we see connectivity as more than just protected corridors, but a landscape matrix that has high permeability. This new indicator, in combination with Indicator 1.1.2, will enable us to monitor progress towards a system of protected areas planning, policy, and management that addresses climate change.

- 3.10. Have extant climate-change impacts made this indicator more pertinent to SFM (i.e. 2.3 and the mountain pine beetle)? These indicators can be placed in category five or considered for conversion from a supporting to a core indicator (where applicable).

Many of the extant climate-change impacts on Canada’s forests discussed in the evaluation of Indicator 1.1.1, such as widespread aspen decline and dieback in the western interior (Hogg et al., 2008) and changing treeline dynamics in the Rocky Mountains (Danby & Hik, 2007), all have major implications for the current network of protected areas in Canada (Scott & Lemieux, 2005).

There are also some interesting examples of climate change affecting non-forested components of protected areas. Glaciers are one of the geomorphological drivers and enduring features that are targeted in protected areas in parks such as Glacier National Park. Climate change has been directly linked the loss of 115 of the 150 within the park, and the remainder are expected to disappear in the coming decades (Hall & Farge, 2003). A prominent example of climate-change impacts in the United States is within Yellowstone National Park, where drought conditions led to a severe wildfire season within the park, directly influencing the forest conditions and leading to an estimated \$60,000,000 USD loss in tourism revenue (Franke, 2000; Scott et al., 2007).

- 3.11. How should the surviving indicator (the original, modified, or new) be modelled and monitored so that stronger SFM signals may be generated?

Data pertaining to forest conditions and wetland area for Indicator 1.1.2 are from Canada's Forest Inventory (CanFI), which is a compilation of existing inventories from Canada's provincial and territorial jurisdictions (CanFI, 2001). CanFI is administered by the CFS and CCFM, and is still actively monitoring forest conditions throughout the country, and will hopefully continue to be a primary data source for the assessment of ecosystem diversity.

The spatial extent of protected areas is derived from a compilation of data sources from Canada's jurisdictions, as well as from the Canadian Conservation Areas Database (CCEA, 2001). These data, could in combination with CanFI data on forest conditions and regional land classification datasets, could also serve in the monitoring and assessment of the newly suggested indicator, *Connectivity of Protected Areas*.

Forecast modelling and remote sensing tools also exist for potential future indicator assessment. Remote sensing using satellite imagery provides an opportunity for monitoring changes in forests within protected areas that is far more feasible than ground-based assessments at the national scale. Forecast modelling is also a useful strategy for tree-species-distribution mapping, that will likely increase in importance with the changing climate as a conservation planning tool (Hannah et al., 2007).

3.12. Does this indicator track an entity whose relationship with climate is regionally variable?

The effects of climate change on Indicator 1.1.2 will be variable by region.

INDICATOR 1.2.1 THE STATUS OF FOREST-ASSOCIATED SPECIES AT RISK

1. Linkages Assessment

Table 1.1. Indicators influencing Indicator 1.2.1.

Indicator 1.2.1	Influencing Indicators
First order positive	1.2.4, 2.3, 3.3, 5.3.1, and 5.3.2
First order negative	1.2.2, 1.2.3, 2.2, 3.2, and 6.4.2
First order bi-directional	1.1.1, 1.1.2, 2.1, 4.1.1, 4.1.2, and 6.5.4

Table 1.2. Indicators influenced by Indicator 1.2.1.

Indicator 1.2.1	Influenced Indicators
First order positive	None
First order negative	None
First order bi-directional	6.5.4

- 1.1. Which indicators are influencing and influenced directly (first-order interactions) by the indicator in question? Is the indicator more of a driver of change in other indicators, or being driven by other indicators?

Indicator 1.2.1 is influenced by 16 other indicators, from all criteria, but primarily from Criterion 1. It only influences one other indicator directly, Indicator 6.5.4. Indicator 1.2.1 is far more driven to change by other indicators than a driver of change in them.

- 1.2. List the indicators described as ‘relevant indicators under other criteria’ in the 2003 C&I-SFM. Is there any conflict with the interactions described in the matrix?

Indicators described as relevant to biological diversity in the 2003 C&I-SFM report include Indicators 2.1, 2.2, 2.3, and 2.5. The condition and productivity of a forest ecosystem is a key driver for the risk-designation of forest-associated species, and as such these were all indicators that were found to influence Indicator 1.2.1 in the interaction matrix.

- 1.3. Are there any overlaps or gaps in the relationship with indicators defined in Eddington and colleague’s (2009) report?

There are five indicators under the *Biodiversity* category in the FFEI indicator set, with Indicator 14 *Species Diversity* pertaining most to Indicator 1.2.1. Climate change will likely present opportunities and pressures for forest-associated species in British Columbia. While environmental change may lead to more high-altitude habitat in the Province, warmer temperatures, especially in the winter, may cause more outbreaks of invasive and exotic forest pests (Eddington et al., 2009). A well-known example of this is the current epidemic of mountain pine beetle (*Dendroctonus ponderosae*) in western Canada (Kurz et

al., 2008). The FFEI Indicator 14 is more concerned with population dynamics and phenology of various species than with risk-status assigned by any legislative or non-governmental body, such as the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) status-designations used in the CCFM assessment of Indicator 1.2.1 (CCFM, 2006).

2. Independent Climate-Change Assessment

2.1. Provide in detail, a qualitative description of what are the expected direct effects of climate change on the indicator, using a broad representation from the literature.

As of the 2005 C&I-SFM national status report, there are 305 COSEWIC-designated species, 219 of which are listed under Schedule 1 of Canada's Species at Risk Act (SARA; CCFM, 2006). By far the most recognized threat to these species-at-risk is habitat loss and destruction (COSEWIC, 2004). Climate change may pose additional threats to these species or interact cumulatively with these already recognized threats like invasive, alien species, declining genetic diversity, unsustainable trade and harvesting, environmental contamination, and of course habitat degradation (COSEWIC, 2004; CCFM, 2006).

There are many different possible effects of climate change on forest-associated species and the level of risk we assign to them that have been explored using simulation modelling, small-scale experimentation, and paleoecological research (McCarty et al., 2001). Some examples include shifts in the distributions of species, temporal changes in phenology and life-histories, more abundant diseases and parasites, and greater competition from invasive, alien species (Hannah et al., 2002; Schneider & Root, 2002; Thomas et al., 2004; Mawdsley et al., 2009; Thompson et al., 2009). Forest-associated fauna that are likely to be highly affected by environmental change are species with lower fecundity, larger ranges and body sizes, and boreal or montane habitats (Thompson et al., 1998; Mawdsley et al., 2009).

2.2. Given expected changes in Canada's climate, describe if and how the indicator's ability to signal progress towards SFM remains unchanged.

Indicator 1.2.1 presents an interesting case where, under the current indicator design, its measurement and validity rely entirely on external factors, which are the COSEWIC assessment processes. Fortunately for the SFM signal of the Indicator, climate change is being more frequently addressed in the COSEWIC status assessment and designation process, as it was recently for the polar bear (*Ursus maritimus*), flammulated owl (*Otus flammeolus*), and whitebark pine (*Pinus albicaulis*; COSEWIC, 2001; COSEWIC, 2008a; COSEWIC, 2008b COSEWIC, 2010). Therefore, the major declines in the predictability and relevance of Indicators 1.2.2 and 1.2.3 are not nearly as significant or detrimental for Indicator 1.2.1. Moreover, this close association with COSEWIC assessments and status reports will likely abate the potential decline in measurability and feasibility caused by the declines in population levels and distribution of these at-risk species.

- 2.3. If an indicator's ability to signal progress towards SFM will be changed, describe if and how the indicator may become worse or better at signalling SFM progress.

Indicator 1.2.1 will not significantly diminish in its ability to signal SFM progress.

3. Integrated Climate-Change Assessment

- 3.1. What are the key determinants of the indicator (i.e. what causes it to change when it does change);

a) Among other indicators in the C&I framework?

- **Indicator 1.2.1 is largely determined by Indicators 1.2.2 and 1.2.3.**
- **The status of forest-associated species-at-risk is also dependent upon conditions and availability of forest habitat. This is determined by Indicators like 1.1.1 and 2.1, but also by major drivers of habitat change and fragmentation that are tracked by Indicators 2.2, 2.3, and 5.3.1.**
- **Competition and mortality caused by invasive alien species, and therefore Indicator 1.2.4, are determinants of Indicator 1.2.1.**
- **Indicator 5.3.2 has the potential to track any unsustainable trade and over-harvest of forest-associated species, and is a determinant of Indicator 1.2.1.**

b) Among determinants not within the C&I framework?

- **The genetic diversity of forest-associated species, especially of isolated populations, is a key determinant of Indicator 1.2.1.**
- **Changes in competitive regimes and the timing of life-history events and life-cycles can result from other stressors on wildlife, such as over-harvesting, and are a determinant of Indicator 1.2.1.**

- 3.2. For what other entities is this indicator a key determinant (i.e. when it changes, what other indicators are influenced to change);

a) Among other indicators in the C&I framework?

- **There is only one other indicator in the C&I framework that is determined by Indicator 1.2.1. This is Indicator 6.5, which may be influenced by the designated**

risk-status of a species, such as resource planning regimes that specifically address woodland caribou (*Rangifer tarandus caribou*) habitats in Ontario and Quebec (Plotkin & McEachern, 2006).

- b) Among determinants not within the C&I framework?
- **The COSEWIC national-status designations of forest-associated species are meant to inform both the public and key decision-makers in government and industry, and are determinants of public awareness.**

3.3. To what degree can we now, on the basis of extant knowledge, establish how the key determinants interact cumulatively in influencing the indicator?

Given that 69% of forest-associated species were under some level of COSEWIC-designated risk in 2005, it is reasonable to assume that many populations of these species will be vulnerable to climatic and environmental change interacting cumulatively with existing threats. Furthermore, the species that have been designated with some level of risk due in-part to climate change are already under many different forms of stress, such as loss of habitat, over-harvesting, and environmental contamination (COSEWIC, 2004).

3.4. Is the indicator largely unrelated to any other, as described by the linkages assessment and evaluation of key determinants? If so, and the indicator was defined as uninfluenced by climate change in the independent assessment, then it can be placed in category one.

Indicator 1.2.1 is not a major driver or determinant for other processes. However, it is influenced by several other indicators within the C&I framework and by external determinants. Given the potential for climate change to influence the risk-status of forest-associated species and the importance of other processes to Indicator 1.2.1, we do not recommend assignment to category one.

3.5. Do the indirect effects of climate change via the linkages with other indicators influence the indicator's ability to signal SFM, regardless of which category was assigned in the independent climate-change assessment?

The major sources of climate-change influence on Indicator 1.2.1 through the linkages with other indicators are increases in the frequency and magnitude of natural disturbance events, as indicated by 2.3, and more frequent outbreaks of invasive, alien forest-associated species, partially indicated by 1.2.4.

- 3.6. If the indicator's ability to signal SFM progress remains the same under a changing climate, can we conclude no negative influence and leave it unchanged? These indicators can be placed in category two.

The ability of Indicator 1.2.1 to signal SFM will not be diminished to the point that indicator modification is necessitated. This Indicator can therefore remain unmodified and be placed in category two, *Unmodified Indicators*.

- 3.7. If the indicator's ability to signal SFM progress deteriorates when one assumes a changing climate, then what modifications are possible or warranted to improve its ability sufficiently for it to remain among the C&I-SFM? These indicators can be placed in category three.

Not applicable.

- 3.8. If no modifications seem possible or warranted, are we ready to recommend abandonment of the indicator? These indicators can be placed in category four.

Not applicable.

- 3.9. If we recommend abandonment, can we identify any new and closely allied indicators that might suit our needs better under climate change? These indicators can be placed in category five.

Not applicable. We do not recommend the creation of a new indicator in place of or pertaining to Indicator 1.2.1.

- 3.10. Have extant climate-change impacts made this indicator more pertinent to SFM (i.e. 2.3 and the mountain pine beetle)? These indicators can be placed in category five or considered for conversion from a supporting to a core indicator (where applicable).

Many different impacts of climate change on global biodiversity have already been observed (Thomas et al., 2004; Mawdsley et al., 2009). More specifically, there are examples of COSEWIC status-updates that have partially attributed their assessments to the changing climate (COSEWIC, 2001; COSEWIC, 2008a; COSEWIC, 2008b; COSEWIC, 2010).

Many forest-associated species rely on particular habitat conditions, which make them more vulnerable to habitat alteration and destruction from many different causes, including climate change. For example, the flammulated owl relies on mature coniferous forest in western Canada. The extent and magnitude of destruction caused by the

mountain pine beetle has seriously degraded the owl's habitat and contributed to the recent designation of Special Concern by COSEWIC (COSEWIC, 2001; COSEWIC, 2008b).

3.11. How should the surviving indicator (the original, modified, or new) be modelled and monitored so that stronger SFM signals may be generated?

The sole data source for Indicator 1.2.1 is the assessment and designation of Canadian wildlife species by the independent committee of experts and researchers that form COSEWIC. Given the acknowledgment and incorporation of climate change by COSEWIC in their assessments, we see no reason for modifying the current approach for measuring and monitoring Indicator 1.2.1.

3.12. Does this indicator track an entity whose relationship with climate is regionally variable?

The regional implications of climate change on forest-associated species and their risk designation, of which there are many, have no consequence for the capacity of Indicator 1.2.1 to signal SFM progress. The complex regional variability of climate-change influence would be addressed in the in-depth COSEWIC assessment and designation.

INDICATOR 1.2.2 POPULATION LEVELS OF SELECTED FOREST-ASSOCIATED SPECIES

1. Linkages Assessment

Table 1.1. Indicators influencing Indicator 1.2.2.

Indicator 1.2.2	Influencing Indicators
First order positive	1.2.3, 1.3.2, 2.2, 2.5, 3.2, and 6.4.2
First order negative	1.2.4, 2.3, 2.4, 3.3, 5.3.1, and 5.3.2
First order bi-directional	1.1.1, 1.1.2, 2.1, 4.1.1, and 4.1.2

Table 1.2. Indicators influenced by Indicator 1.2.2.

Indicator 1.2.2	Influenced Indicators
First order positive	1.2.3, 2.3, and 5.3.2
First order negative	1.2.1, 2.1, 2.5, 4.1.1, and 4.1.2
First order bi-directional	1.1.1 and 1.1.2

- 1.1. Which indicators are influencing and influenced directly (first-order interactions) by the indicator in question? Is the indicator more of a driver of change in other indicators, or being driven by other indicators?

Indicator 1.2.2 influences 10 other indicators, which mainly pertain to some condition of forest habitat that forest-associated species can alter with high populations. It is influenced by 17 indicators, from all Criteria. Indicator 1.2.2 is more influenced by other indicators than it is a driver of change in them.

- 1.2. List the indicators described as ‘relevant indicators under other criteria’ in the 2003 C&I-SFM. Is there any conflict with the interactions described in the matrix?

Indicators described as relevant to biological diversity in the 2003 C&I-SFM report include 2.1, 2.2, 2.3, and 2.5. The condition and productivity of a forest ecosystem is a key driver of species abundance and distribution, and as such these are all indicators influencing Indicator 1.2.2 in the interaction matrix. Furthermore, Criterion 2 was found to have both high direct and indirect influence over Indicator 1.2.2.

- 1.3. Are there any overlaps or gaps in the relationship with indicators defined in Eddington and colleague’s (2009) report?

There are five indicators under the biodiversity category in the FFEI indicator set, with Indicator 14 *Species Diversity* being the most relevant to Indicator 1.2.2. The rationale behind Indicator 14 is to track both the possible opportunities and pressures for forest-associated species in British Columbia due to climate change. With the diverse topography of British Columbia, there will likely be an increase in potential high-altitude habitat, yet

warmer climates may also favour invasive and alien species, as it has with the invasive mountain pine beetle (*Dendroctonus ponderosae*) outbreak (Kurz et al., 2008; Eddington et al., 2009). There is a fair amount of overlap between Indicator 14 and Element 1.2, including Indicator 1.2.2. One divergence is the broader and more flexible monitoring approach suggested by Eddington and colleagues (2009), whereby a wide array of species is monitored, as opposed to select large mammal and bird species in the CCFM 2005 national status report. This was done in order to account for the fluctuating availability of data pertaining to populations of forest-associated species and the high cost of monitoring efforts.

2. Independent Climate-Change Assessment

- 2.1. Provide in detail, a qualitative description of what are the expected direct effects of climate change on the indicator, using a broad representation from the literature.

Climate change poses a serious threat to many aspects of biodiversity, including forest-associated species and their abundance, and existing impacts have already been documented in Canada and around the globe (Gitay et al., 2002; Hannah et al., 2002; Thomas et al., 2004; Mawdsley et al., 2009). Climate change has the potential to affect the abundance of forest-associated species, especially boreal and montane species (Mawdsley et al., 2009) and species with larger body sizes and broader ranges (Thompson et al., 1998). In their assessment of climate change and the forest landscape in Ontario, Thompson and colleagues (1998) argue that all forest-associated species that respond to changes in forest patch size and structure will be affected by climate change. Population changes of forest-associated species may be induced by changes in habitat, competitive regimes, survival and fecundity, the timing of life-history events, invasive and exotic species populations, natural disturbance regimes, and disease dynamics, in addition to the direct effects from elevated temperatures (Thompson et al., 1998; Schneider & Root, 2002; Mawdsley et al., 2009).

The vast majority of climate-change impacts will likely affect the population levels of forest-associated species indirectly, both via other indicators within the C&I framework and external determinants, which will be addressed in the integrated climate-change assessment. Change in species' distributions or ranges is one of the more recognized effects of climate change (Hannah et al., 2002; Thomas et al., 2004; Malcom et al., 2006), which is closely related to species abundance. Potential forest habitat is far from spatially continuous and connected across Canada, so these climate-driven changes in distribution could have serious implications for the population levels of forest-associated species because of the existing barriers to dispersal (CCFM, 2006). Climate-induced changes in natural disturbance regimes and populations of invasive and exotic species is another frequently predicted impact of climate change (Dale et al., 2001; Williamson et al., 2009), which will also have serious implications for Indicator 1.2.2.

The potential impacts of climate change on moose (*Alces alces*) and white-tailed deer (*Odocoileus virginianus*) provide a useful example of the variability and complexity of the effects of climate change on wildlife. Both species require a mix of young forest for

browsing and old forest, particularly old coniferous forest, for shelter from summer heat and deep winter snow (Thompson et al., 1998). Deer populations will likely benefit from warmer winter temperatures and reduced winter snow depth, potentially making more northern habitat available to them. Conversely, moose populations cannot tolerate high summer temperatures (another predicted impact of climate change) and new habitat overlap with deer will subject them more frequently to a fatal parasite carried by the deer (Anderson & Lancaster, 1974).

Far more important than discerning each forest-associated species' response to climate change is the recognition that there will be change induced by the altered climate, and that these changes will be variable across species and regions. Furthermore, a direct cause and effect relationship with the changing climate is incredibly difficult to discern, given the additional stressors of habitat loss/fragmentation and harvesting in the form of hunting and trapping (CCFM, 2006).

2.2. Given expected changes in Canada's climate, describe if and how the indicator's ability to signal progress towards SFM remains unchanged.

The ability of Indicator 1.2.2 to signal progress towards SFM will be changed. It is apparent in current research that there will be significant influence of climate change the population levels of forest-associated species.

2.3. If an indicator's ability to signal progress towards SFM will be changed, describe if and how the indicator may become worse or better at signalling SFM progress.

Climatic change will most likely compromise the ability of Indicator 1.2.2 to signal SFM in Canada. Because climate change may cause both increases and decreases in the population levels of forest-associated species, both directly and indirectly and often in an unpredictable manner, the responsiveness of these indicator species and their relevance to SFM are severely reduced. We can no longer confidently infer that changes in populations can be attributed to forest management activities or signal SFM without addressing the role of climate change, as these forest-associated species no longer have static relationships with forest management and with the spatial distribution of habitat in Canada. Indicator species are selected because they rely on particular forest conditions for their habitat, and as such an increase or decrease in these conditions should lead to a corresponding and predictable response in population levels. It is now predicted that these habitat conditions will be altered in response to climate change (one of many possible climate-change impacts on wildlife), so the population levels of these species may be highly sensitive to drivers of change that are variable, unpredictable, or uncertain, and external to SFM. Therefore, the predictability, responsiveness, and relevance of Indicator 1.2.2 is compromised by climate change. It is also possible that there will be a decline in the measurability and feasibility of some indicator species if their population levels decline to the point where measurement is impeded.

3. Integrated Climate-Change Assessment

3.1. What are the key determinants of the indicator (i.e. what causes it to change when it does change);

a) Among other indicators in the C&I framework?

- **Indicator 1.2.2 is influenced by 17 other indicators from the C&I framework. of these, indicators within Criteria 2 that describe the condition and productivity of forest ecosystems appear to be the most important determinants of Indicator 1.2.2, as they track the condition of the habitat for forest-associated species.**
- **Human activities, including those arising from forest management, are key determinants for the population levels of many forest-associated species, as tracked by Indicators 2.2, 5.3.1, and 5.3.2.**
- **Compliance with SFM standards and guidelines, tracked by Indicators 3.2 and 6.4.2, is an important determinant for Indicator 1.2.2.**

b) Among determinants not within the C&I framework?

- **Many determinants not directly tracked by indicators in the C&I framework can lead to changes in the populations levels of forest-associated species. These might include anthropogenic stressors like development, urbanization, agriculture, and other causes of fragmentation, and unregulated over-harvesting of species.**
- **Biological determinants like natural population cycles, *inter*- and *intra*-specific competition, and introduced invasive competitors, disease, and parasites (that are unrelated to SFM and therefore not monitored by the C&I framework) are determinants of Indicator 1.2.2.**
- **Declines in genetic diversity had also been linked with population-level declines of many different species (Schneider & Root, 2002).**

3.2. For what other entities is this indicator a key determinant (i.e. when it changes, what other indicators are influenced to change);

a) Among other indicators in the C&I framework?

- **Given that Indicator 1.2.2 is a condition/response indicator, there are few entities for which it is a key determinant. The most obvious among the indicator set is Indicator 1.2.1 *the Status of Forest-Associated Species at Risk*, which is directly associated with populations levels/abundance of these species.**

- **Indicator 1.2.2 is also likely both a determinant and determined by Indicator 1.2.3 *Distribution of Selected Forest-Associated Species*.**
- **Forest-dwelling species are determinants of their habitat, and thus of Indicators tracking some type of habitat condition, such as Indicators 1.1.1 and 2.1**

b) Among determinants not within the C&I framework?

- **The abundance of forest-associated species is a driver of many complex ecosystem processes and relationships not included within the C&I framework, such as a given species' role within a food web, as keystone species, or as top predators, as well the existence of co-evolved and symbiotic relationships with other species.**
- **Healthy populations are also important indicators of genetic diversity (Mills & Smouse, 1994).**
- **Many of the less tangible non-timber forest products and forest-based services are addressed in Criteria 5 and 6. However, the full value of healthy populations of forest-associated species to Aboriginal peoples, traditional land lifestyles, tourism, recreation, and the inherit value of biodiversity cannot be represented fully in the C&I framework.**

3.3. To what degree can we now, on the basis of extant knowledge, establish how the key determinants interact cumulatively in influencing the indicator?

We can certainly assume that these determinants interact cumulatively, but it is exceedingly difficult to discern to what extent they interact, and whether the sum of the determinants may be larger than its parts (Theobald et al., 1997). For example, habitat fragmentation from development, agriculture, and forest management may isolate populations of species and lead to declines in genetic diversity and finally declines in population levels due to inbreeding (Mills & Smouse, 1994). Climate change may be an additional stressor on population levels that could make them more vulnerable to existing stressors and contribute to the cumulative influence of the determinants on Indicator 1.2.2.

3.4. Is the indicator largely unrelated to any other, as described by the linkages assessment and evaluation of key determinants? If so, and the indicator was defined as uninfluenced by climate change in the independent assessment, then it can be placed in category one.

Indicator 1.2.2 is highly related to other indicators in the C&I framework and to external determinants of change. We do not recommend assigning it to category one.

- 3.5. Do the indirect effects of climate change via the linkages with other indicators influence the indicator's ability to signal SFM, regardless of which category was assigned in the independent climate-change assessment?

Climate change will likely influence Indicator 1.2.2 via direct interactions, such as physiological stress on species like moose due to increases in temperature, but also through many indirect interactions. These indirect effects of climate change include both increases and decreases in the amount of habitat, change in habitat conditions, shifts in species distributions, more frequent and severe natural disturbances, more invasive and exotic species, diseases, pests, and parasites, and changes in life-history events, survival, and fecundity. Some of these are represented by existing indicators in the C&I framework, like Indicator 2.3 and 2.2, while others such as changes in survival and fecundity of forest-associated species are not.

- 3.6. If the indicator's ability to signal SFM progress remains the same under a changing climate, can we conclude no negative influence and leave it unchanged? These indicators can be placed in category two.

Not applicable. The ability of Indicator 1.2.2 to signal SFM progress will deteriorate with climate change.

- 3.7. If the indicator's ability to signal SFM progress deteriorates when one assumes a changing climate, then what modifications are possible or warranted to improve its ability sufficiently for it to remain among the C&I-SFM? These indicators can be placed in category three.

Species diversity, especially the population levels of forest-associated species, is one of the most approachable methods to assess and monitor biodiversity (CCFM, 2003). The fundamental goal of this indicator will likely not need to change. Instead, which species are monitored and the approach to data collection and measurement should be modified to address climate change.

Some alteration to those species that are monitored in the assessment of Indicator 1.2.2 may be necessary. This might include selecting new species for monitoring, as well as the strong possibility of abandoning some species if their response to climate change is such that they no longer are an ideal indicator of SFM. Ideal species to monitor for this indicator will either be unaffected or mildly affected by climate change, or have a climate change response that is adequately understood so that the indicator species' predictability and responsiveness, and relevance to SFM is not greatly reduced. The goal is to avoid a case of a forest-associated species being monitored in which its relationship with climate change is not understood or it is cumulatively influenced by so many determinants in addition to climate change that any changes in population levels lose their relevance to SFM.

- 3.8. If no modifications seem possible or warranted, are we ready to recommend abandonment of the indicator? These indicators can be placed in category four.

Not applicable. While climate change may warrant the removal of one or more species from monitoring efforts, Indicator 1.2.2 is still highly important for monitoring and assessing threats to biodiversity.

- 3.9. If we recommend abandonment, can we identify any new and closely allied indicators that might suit our needs better under climate change? These indicators can be placed in category five.

Not applicable. However, we may add species to the list of those monitored, especially if their population levels are either highly robust to changes in climate, or their response to climate change is intensely researched with high data availability.

- 3.10. Have extant climate-change impacts made this indicator more pertinent to SFM (i.e. 2.3 and the mountain pine beetle)? These indicators can be placed in category five or considered for conversion from a supporting to a core indicator (where applicable).

There are examples in the literature of forest-associated species that have been affected by the changing climate (Pounds et al., 2006; Mawdsley et al., 2009). These examples may improve the relevance of Indicator 1.2.2, as they contribute to our understanding of the impacts of climate change on biological diversity. Monitoring forest-associated species that may now be threatened by climate change is an important task and will have a vital role in future biodiversity conservation. However, the objective of the C&I framework is to monitor forest-associated species in order to signal our progress towards SFM. It is important to differentiate between these two tasks, as the latter guides our climate change evaluation of this Indicator

- 3.11. How should the surviving indicator (the original, modified, or new) be modelled and monitored so that stronger SFM signals may be generated?

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) is the primary data source for all indicators within Element 1.2. In their recent assessments of species like the flammulated owl (*Otus flammeolus*) in British Columbia, COSEWIC has addressed the potential threat of environmental change on forest-associated species, and will therefore remain a valuable asset to future C&I-SFM assessments. Current research on the impacts of climate change on biological diversity may invalidate or shed light on the value of monitoring new and existing species under Indicator 1.2.2.

- 3.12. Does this indicator track an entity whose relationship with climate is regionally variable?

The relationship of Indicator 1.2.2 with Canada's 15 terrestrial ecozones is complex in nature. While the distribution and abundance of forest-associated species is certainly influenced by the biological and geophysical factors that differentiate ecozones, these species are not restricted by their boundaries. The population levels of forest-associated species are more likely to be sensitive to changes in climate at the extremes of their ranges, and in regions where populations are already affected by existing stressors, such as habitat fragmentation and over-harvesting (Mawdsley et al., 2009). As such, the regional variation of climate-change influence over Indicator 1.2.2 does not warrant further modification of the Indicator.

INDICATOR 1.2.3 DISTRIBUTION OF SELECTED FOREST-ASSOCIATED SPECIES

1. Linkages Assessment

Table 1.1. Indicators influencing Indicator 1.2.3.

Indicator 1.2.3	Influencing Indicators
First order positive	1.2.2, 1.3.2, 2.2, 2.5, 3.2, and 6.4.2
First order negative	1.2.4, 2.3, 2.4, 3.3, 5.3.1, and 5.3.2
First order bi-directional	1.1.1, 1.1.2, 4.1.1, and 4.1.2

Table 1.2. Indicators influenced by Indicator 1.2.3.

Indicator 1.2.3	Influenced Indicators
First order positive	1.2.2 and 2.3
First order negative	1.2.1, 2.1, 2.5, 4.1.1, and 4.1.2
First order bi-directional	1.1.1 and 1.1.2

- 1.1. Which indicators are influencing and influenced directly (first-order interactions) by the indicator in question? Is the indicator more of a driver of change in other indicators, or being driven by other indicators?

Indicator 1.2.3 influences nine other indicators, all of which pertain to some condition of forest habitat that forest-associated species might affect. It is influenced by 16 other indicators from every Criterion. Indicator 1.2.3 is more influenced by other indicators than a driver of change in them.

- 1.2. List the indicators described as ‘relevant indicators under other criteria’ in the 2003 C&I-SFM. Is there any conflict with the interactions described in the matrix?

Indicators 2.1, 2.2, 2.3, and 2.5 are all deemed relevant to biological diversity in the 2003 C&I-SFM report. These are all Indicators found to have first-order interactions with Indicator 1.2.3 in the interaction matrix.

- 1.3. Are there any overlaps or gaps in the relationship with indicators defined in Eddington and colleague’s (2009) report?

of the five indicators within the *Biodiversity* category of the FFEI indicator set, Indicator 14 *Species Diversity* is the most relevant to Indicator 1.2.3. There is a fair amount of overlap between Indicator 14 and Element 1.2, especially with Indicators 1.2.2 and 1.2.3. However, the FFEI project is more broad and flexible in their monitoring approach, with a wide array of species that are monitored, in contrast to the more detailed case studies of four forest-associated species in the CCFM 2005 C&I-SFM national status report (CCFM,

2006). The rationale behind the FFEI approach was to mitigate the monitoring difficulties associated with fluctuating data availability and high costs of data collection.

2. Independent Climate-Change Assessment

- 2.1. Provide in detail, a qualitative description of what are the expected direct effects of climate change on the indicator, using a broad representation from the literature.

The approach taken in the assessment of Indicator 1.2.3 in 2005 (CCFM, 2006) was detailed case studies of four selected forest-associated species: the woodland caribou (*Rangifer tarandus caribou*), American marten (*Martes americana*), pileated woodpecker (*Dryocopus pileatus*), and northern goshawk (*Accipiter gentilis*). Consequently, we saw it fitting to address the influence of climate change on each of these four species, with a focus on the well-studied woodland caribou.

The woodland caribou is highly sensitive to habitat fragmentation, as it relies on large tracts of intact and mature forest habitat, and is seen as an indicator of forest connectivity (CCFM, 2006). of the five major woodland caribou populations, three have been nationally designated as at-risk since the 1980's (Kelsall, 1984). Four of five populations are now listed under Schedule 1 of Canada's Species at Risk Act (Government of Canada, 2009).

There is a strong possibility for climate-change impacts to interact cumulatively with the extant stressors facing these stressed populations of woodland caribou. In addition to the likelihood of habitat change caused by shifting ranges of tree species and changes in natural disturbance regimes, there is also a high likelihood that climate change will affect the winter forage of woodland caribou (Chowns, 2003). Caribou have a strong relationship with the presence and distribution of lichen, an adaptation that has allowed them to occupy nutrient-poor niches in the forest landscape, but that makes them highly dependent upon the abundance of lichen, especially in the winter months when other plant material is unavailable (Thomas, 1998). This strong dependency on winter forage makes woodland caribou highly vulnerable to changes in snowpack and winter snow dynamics, and thus vulnerable to climate change (Tyler, 2010). This is because range-icing and thick snow crusts can block feeding access to lichens and other plant material (Bradshaw et al., 1995; Tyler, 2010).

American marten are forest-dwelling members of the weasel family whose habitat requirements are dense conifer forests with sufficient levels of deadwood (Chapin et al., 1998). Marten and other old-growth dependent species like the northern goshawk will more than likely be influenced by climate-driven environmental change. For example, in British Columbia, marten populations are expected to experience major declines due to the mountain pine beetle infestation and subsequent salvage harvests (Steventon & Daust, 2009). Conversely, the pileated woodpecker is expected to benefit from climate change in parts of its range due to warmer winter temperatures (Matthews et al., 2004).

- 2.2. Given expected changes in Canada's climate, describe if and how the indicator's ability to signal progress towards SFM remains unchanged.

Because of the narrow focus of Indicator 1.2.3 on four forest-associated species with in-depth case studies, we feel that there is a level of monitoring and assessment rigour afforded that will minimize the decline of this Indicator's ability to track SFM progress. The description above suggests that there is very likely to be effects of climate change on these select forest-associated species. However, the decline in Indicator predictability, responsiveness, and relevance will be far less severe than with Indicator 1.2.2. We argue that the availability of information on these four species measured under Indicator 1.2.3 will outweigh any declines in Indicator ability due to uncertain or extreme species' response to climate change.

- 2.3. If an indicator's ability to signal progress towards SFM will be changed, describe if and how the indicator may become worse or better at signalling SFM progress.

The ability of Indicator 1.2.3 to signal progress towards SFM will not be diminished to any significant degree.

3. Integrated Climate-Change Assessment

- 3.1. What are the key determinants of the indicator (i.e. what causes it to change when it does change);

- a) Among other indicators in the C&I framework?
 - **Indicators from Criteria 2 are key determinants of Indicator 1.2.3 because they describe the condition of forest habitat for these four species, all of which have specific forest-habitat requirements.**
 - **The area, cover-type, and age structure of Canada's forests largely determine the extent of available habitat for these forest-associated species. Moreover, forest ecosystems within protected areas offer important refuges for many wildlife species. Therefore, Indicators 1.1.1 and 1.1.2 are key determinants of Indicator 1.2.3.**
 - **Competition and mortality caused by invasive, alien species are limiting factors for the distribution of forest-associated species, and therefore Indicator 1.2.4 is in part a determinant of Indicator 1.2.3.**

- b) Among determinants not within the C&I framework?

- **Biological determinants like *inter*- and *intra*-specific competition and introduced invasive competitors, disease, and parasites (not included in the C&I framework) are determinants of Indicator 1.2.3.**
- **Other types of anthropogenic stressors on these species, such as over-hunting and over-trapping, are also determinants of their distribution.**
- **Climate, especially winter climate, is a determinant of the distribution of woodland caribou and many other large forest-dwelling mammals.**

3.2. For what other entities is this indicator a key determinant (i.e. when it changes, what other indicators are influenced to change);

a) Among other indicators in the C&I framework?

- **Probably the most closely related indicator to Indicator 1.2.3 is Indicator 1.2.2, which is directly linked to the distribution of forest-associated species.**
- **Forest-dwelling species are determinants of their habitat, and thus of Indicators tracking some type of habitat condition, such as Indicators 1.1.1 and 2.1.**

b) Among determinants not within the C&I framework?

- **Forest-associated species often play a role in many complex ecosystem processes and relationships not included within the C&I framework. A perfect example is the pileated woodpecker, which as a primary cavity excavator species creates nesting sites for a myriad of forest fauna, including the American marten.**
- **There are numerous social and economic benefits associated with forest wildlife that are only moderately addressed in Criteria 5 and 6. The full societal value of healthy, widely distributed populations of these four forest-associated species to Aboriginal peoples, traditional lifestyles, tourism, recreation, and the inherent value of biodiversity are impossible to fully delineate and monitor.**

3.3. To what degree can we now, on the basis of extant knowledge, establish how the key determinants interact cumulatively in influencing the indicator?

Declines in the distribution of many forest-associated species, such as the four discussed here, are most often caused by the cumulative interaction of many stressors. Woodland caribou for example, rely on large intact areas of forest habitat with many specific needs, most-notably the presence of old-growth dependent lichens (Thomas, 1998).

Northern populations are believed to be in decline due to the combination of human disturbance and predation, while boreal populations are frequently faced with intense development, where the remnant fragmented populations are faced with the introduction of parasites, changes in predator-prey dynamics, and overexploitation attributed to better access for hunters (Chowns, 2003).

A frequent cumulative effect on these forest-associated species that rely on particular habitat conditions or have extensive ranges is that they are under stress due to habitat fragmentation from human activities, and thus susceptible to additional stressors like introduced disease and parasites, over-hunting/trapping, and in all likelihood, climate change.

- 3.4. Is the indicator largely unrelated to any other, as described by the linkages assessment and evaluation of key determinants? If so, and the indicator was defined as uninfluenced by climate change in the independent assessment, then it can be placed in category one.

Indicator 1.2.3 is highly related to other indicators in the C&I framework and to external determinants of change. We do not recommend assignment to category one.

- 3.5. Do the indirect effects of climate change via the linkages with other indicators influence the indicator's ability to signal SFM, regardless of which category was assigned in the independent climate-change assessment?

The chief indirect source of climate-change influence on the distribution of these four species is habitat degradation and loss. The loss of forest area due to shifting ranges and dieback and the more frequent and severe natural disturbances are predicted to severely impede the distribution of these species. Forest fire especially is a concern for species with large habitat requirements or old-growth dependence like the woodland caribou and the northern goshawk, respectively (Romme & Turner, 1991; Chowns, 2003). A decline in prey and forage is another possible threat from climate change. Slow lichen recovery and inaccessible winter forage due to snow crust and icing are predicted threats to woodland caribou (Tyler, 2010).

- 3.6. If the indicator's ability to signal SFM progress remains the same under a changing climate, can we conclude no negative influence and leave it unchanged? These indicators can be placed in category two.

There is a chance that the relevance of these four species to SFM and the predictability of Indicator 1.2.3 may deteriorate with climate change. The more in-depth approach to monitoring of these indicator species in comparison to those measured under Indicator 1.2.2 suggests that the SFM signal of Indicator 1.2.3 will be highly dependent on the state of knowledge around the woodland caribou, American marten, pileated woodpecker, and northern goshawk, and their response to the changing climate. Assuming that these four

species remain as indicator species for future assessments, we feel that the high availability of data and publications dictates that that Indicator 1.2.3 should remain unmodified.

- 3.7. If the indicator's ability to signal SFM progress deteriorates when one assumes a changing climate, then what modifications are possible or warranted to improve its ability sufficiently for it to remain among the C&I-SFM? These indicators can be placed in category three.

While we do not recommend modification Indicator 1.2.3, we caution to keep the recommendations from the evaluation of Indicator 1.2.2 in mind. The issue remains that climate change will affect many forest-associated species at varying severities (Schneider & Root, 2002). The major threat to the ability of Indicator 1.2.2 and 1.2.3 to signal SFM progress is the possibility that climate change will blur the relationship of forest-associated species to their current habitat needs and thus diminish their responsiveness and relevance. However, for the reasons discussed above, we do not feel that the design of Indicator 1.2.3 is under immediate threat from climate change, and consequently it should not be modified.

- 3.8. If no modifications seem possible or warranted, are we ready to recommend abandonment of the indicator? These indicators can be placed in category four.

Not applicable. We do not recommend that abandonment of Indicator 1.2.3.

- 3.9. If we recommend abandonment, can we identify any new and closely allied indicators that might suit our needs better under climate change? These indicators can be placed in category five.

Not applicable. However, if emerging knowledge suggests that climate change affects any of these four species in a manner that diminishes their capacity to act as indicators of SFM, we may wish to re-assess whether a new species would be more appropriate for the assessment of Indicator 1.2.3.

- 3.10. Have extant climate-change impacts made this indicator more pertinent to SFM (i.e. 2.3 and the mountain pine beetle)? These indicators can be placed in category five or considered for conversion from a supporting to a core indicator (where applicable).

There are several extent examples in the literature of forest-associated species that have been negatively affected by climate change (Malcolm et al., 2006; Mawdsley et al., 2009). One that pertains directly to woodland caribou is the changes in permafrost in Canada. The loss of permafrost due to the warming temperatures in the western boreal forest has caused changes in nutrient-poor permafrost peatlands, which are critical wintering habitat for woodland caribou in the northern portion of their range (Vitt et al., 2010).

3.11. How should the surviving indicator (the original, modified, or new) be modelled and monitored so that stronger SFM signals may be generated?

The case-study approach to assessing Indicator 1.2.3 facilitates a depth of analysis that will be highly valuable in future assessments under climate change. Sources of data for these four well-known species are ample, and now recognize the threat of global environmental change. These sources include the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) status reports and assessments, provincial and regional Conservation Data Centres, and the scientific literature.

3.12. Does this indicator track an entity whose relationship with climate is regionally variable?

Far more important than the regional variations in the response of these species to environmental change is the response of the individual species, and of the different recognized populations, which are genetically unique and often stressed by different anthropogenic threats.

INDICATOR 1.2.4 NUMBER OF INVASIVE, EXOTIC FOREST-ASSOCIATED SPECIES

1. Linkages Assessment

Table 1.1. Indicators influencing Indicator 1.2.4.

Indicator 1.2.4	Influencing Indicators
First order positive	2.2 and 2.4
First order negative	1.3.2
First order bi-directional	None

Table 1.2. Indicators influenced by Indicator 1.2.4.

Indicator 1.2.4	Influenced Indicators
First order positive	1.2.1, 1.3.2, 2.3, and 3.3
First order negative	1.2.2, 1.2.3, 2.1, 2.2, 2.4, 4.1.1, and 4.1.2
First order bi-directional	1.1.1 and 1.1.2

- 1.1. Which indicators are influencing and influenced directly (first-order interactions) by the indicator in question? Is the indicator more of a driver of change in other indicators, or being driven by other indicators?

Indicator 1.2.4 is only influenced by three indicators, Indicators 2.2, 2.4, and 1.3.2. It influences 13 other indicators, the majority of which are from Criterion 1, and all of them are biophysical indicators. Indicator 1.2.4 is far more of a driver of change in other indicators than it is driven to change.

- 1.2. List the indicators described as ‘relevant indicators under other criteria’ in the 2003 C&I-SFM. Is there any conflict with the interactions described in the matrix?

Indicators 2.1, 2.2, 2.3, and 2.5 are all deemed relevant to biological diversity in the 2003 C&I-SFM report. These are all Indicators found to be influenced by Indicator 1.2.4 in the interaction matrix.

- 1.3. Are there any overlaps or gaps in the relationship with indicators defined in Eddington and colleague’s (2009) report?

Indicator 1.2.4 is most closely related to Indicator 8 *Insects and Diseases* within the *Natural Disturbance* category of the FFEI indicator set. A clear divergence from Indicator 1.2.4 is the inclusion of native insects and diseases in addition to introduced ones, likely in response to the role of climate change in the recent epidemic of mountain pine beetle (*Dendroctonus ponderosae*). Another major difference is the monitoring of invasive, alien plant species in addition to insects and pathogens in the assessment of Indicator 1.2.4, though the main focus in the 2005 C&I-SFM assessment was on introduced forest insects (CCFM, 2006a).

2. Independent Climate-Change Assessment

- 2.1. Provide in detail, a qualitative description of what are the expected direct effects of climate change on the indicator, using a broad representation from the literature.

Invasive alien species are believed to be the second greatest threat to biological diversity, after habitat loss and degradation (CCFM, 2006a). The increase of global trade has enabled flora and fauna to overcome major geographic barriers to dispersal that have historically inhibited their migration.

Forest insect pests and pathogens are perhaps the most extensive and influential group of invasive species on forest ecosystems (Frelich, 2002). Insect outbreaks alter forest ecosystems significantly, causing widespread ecological and economic damage (Fleming & Candau, 1998). Invasive plant species are also highly detrimental to forest ecosystem conditions and biological diversity (Dukes et al., 2009). Within forests, these invasive species of vines and shrubs colonize the understory and outcompete native vegetation, severely affecting understory regeneration and native shrub and herb diversity (Hunter & Mattice, 2002; Burdvig & Evans, 2006).

Climate change is predicted to directly affect the life-cycles and dynamics of invasive, alien species through changes in temperature and precipitation regimes, and indirectly via changes to the dynamics of native predators and competitors, and of host populations, due to changes in the distribution of native tree species (McKenney et al., 2007; Dukes et al., 2009). Despite high levels of uncertainty, the general consensus in the literature is that the changes in climate will favour introduced, invasive species and increase their effects on forest structure and composition, as warmer temperatures can increase the rate of survival, reproduction, and metabolism of these species (Ayres & Lombardero, 2000; Dale et al., 2001; Logan et al., 2003; Dukes et al., 2009).

The definitions of invasive species are variable, but generally refer to species with rapid reproduction and dispersal rates that are outside of their natural range, which most often applies to introduced, alien species. However, native forest pests that break from the control of predation and competition or expand beyond their normal range can also be important sources of forest disturbance. The current epidemic of mountain pine beetle in western Canada (Kurz et al., 2008) or the predicted increase in the extent and severity of spruce budworm outbreaks in eastern Canada (Gray, 2008) are examples of the threat from native species that fit with the definition of invasive in light of climate-induced changes in their dynamics.

- 2.2. Given expected changes in Canada's climate, describe if and how the indicator's ability to signal progress towards SFM remains unchanged.

The ability of Indicator 1.2.4 to signal our progress towards SFM will not remain the same under climate change.

- 2.3. If an indicator's ability to signal progress towards SFM will be changed, describe if and how the indicator may become worse or better at signalling SFM progress.

Climate change may degrade the ability of Indicator 1.2.4 to signal SFM progress by drastically reducing the predictability of the Indicator while increasing its relevance. Moreover, the current design of Indicator 1.2.4 may not be sufficient to track the expected increases in the frequency, severity, and extent of outbreaks of invasive forest pests, both native and alien. The number of invasive, alien species provides useful insight into SFM progress, but it does not give sufficient information on the extent and severity of disturbance on forest ecosystems. Given the growing relevance of invasive species to SFM under climate change, we may need more depth and detail in the indicator pertaining to invasive, forest-associated species.

3. Integrated Climate-Change Assessment

- 3.1. What are the key determinants of the indicator (i.e. what causes it to change when it does change);

a) Among other indicators in the C&I framework?

- **Changes and types of land-use patterns in both forested and non-forested areas are important determinants of Indicator 1.2.4, as represented by Indicator 2.2.**
- **Disturbed and degraded forests are more vulnerable to invasive insects, pathogens, and plants. This makes Indicators 2.3 and 2.4 important determinants of invasive-species dynamics, though not specifically a determinant of the actual number of invasive species.**

b) Among determinants not within the C&I framework?

- **By far the most important determinant of invasive, alien species is the increase in global trade and travel, which is the chief mechanism for alien-species introduction (Gray, 2010).**
- **Origins of the wide array of different invasive, alien species in Canada are highly variable, ranging from the deliberate introduction of Norway maple (*Acer platanoides*) for urban-forest plantings across Canada, to the accidental introduction of brown spruce longhorn beetle (*Tetropium fuscum*) from wooden packaging material in the Port of Halifax (Smith & Hurley, 2000).**

- 3.2. For what other entities is this indicator a key determinant (i.e. when it changes, what other indicators are influenced to change);

- a) Among other indicators in the C&I framework?
- **Invasive species alter forest structure and composition, making them a determinant of Indicators 1.1.1 and 1.1.2.**
 - **Invasive, alien species are a major determinant of and threat to biological diversity, and thus a determinant for nearly every indicator within Criterion.**
 - **Dense understory thickets of invasive plants can halt forest regeneration, influencing Indicator 2.5, and if very severe, Indicator 2.2.**
 - **Disturbance from invasive, alien species increases the vulnerability of forests to other forms of natural disturbance, and often necessitate salvage harvests, making Indicator 1.2.4 a partial determinant of Indicator 2.3.**

- b) Among determinants not within the C&I framework?
- **Invasive forest-associated species are highly detrimental to all native plant diversity, not just trees, and are therefore determinants of forest ecosystem function and the flow of timber and non-timber resources.**

3.3. To what degree can we now, on the basis of extant knowledge, establish how the key determinants interact cumulatively in influencing the indicator?

The number of invasive, alien forest-associated species is a result of many cumulative processes. The growing global trade of commodities and the movement of people, as well as urbanization and land-use change are drivers of invasive-species introduction, while natural disturbances, forest management, and other types of natural resource exploitation make forest ecosystems more vulnerable to establishment and spread (Gray, 2010).

3.4. Is the indicator largely unrelated to any other, as described by the linkages assessment and evaluation of key determinants? If so, and the indicator was defined as uninfluenced by climate change in the independent assessment, then it can be placed in category one.

Indicator 1.2.4 is highly influential on many other indicators within the C&I framework and is related to many other external determinants of change.

3.5. Do the indirect effects of climate change via the linkages with other indicators influence the indicator's ability to signal SFM, regardless of which category was assigned in the independent climate-change assessment?

Climate change may indirectly influence the level of forest disturbance caused by invasive, alien species due to changes in natural disturbance regimes and changes in both host-species dynamics and predator/competitor-species dynamics (Dukes et al., 2009). However, the number of different invasive, alien forest-associated species is determined largely by factors that are external to climate, such as global trade and travel.

- 3.6. If the indicator's ability to signal SFM progress remains the same under a changing climate, can we conclude no negative influence and leave it unchanged? These indicators can be placed in category two.

Not applicable. The ability of Indicator 1.2.4 to signal SFM progress will deteriorate with climate change.

- 3.7. If the indicator's ability to signal SFM progress deteriorates when one assumes a changing climate, then what modifications are possible or warranted to improve its ability sufficiently for it to remain among the C&I-SFM? These indicators can be placed in category three.

Invasive, alien forest-associated species will likely become more abundant and detrimental to forest ecosystems and the sustainable flow of their resources under climate change. In order to fully monitor and assess their potential worsening implications, we feel it will be necessary to modify Indicator 1.2.4. We recommend *Area of Forest Disturbed by Native and Alien Invasive Forest-Associated Species* as the modified indicator. The impetus behind the switch to measuring area-disturbed rather than the number-of-species is that it can be more easily aligned with a directional goal statement; the minimization of forest area disturbed by invasive species. This modification will also serve to reduce the decline in indicator predictability under climate change.

Recent outbreaks of the native mountain pine beetle that has far exceeded all previous outbreaks in severity and extent is partially attributable to the warming winter temperatures (Kurz et al., 2008). This is just one example of how climate change may destabilize the population dynamics of native forest-associated biological disturbance agents, and suggests that we should include what Dukes and colleagues (2009) refer to as native 'nuisance species' in Indicator 1.2.4. This is because climate change has the potential to alter their life-cycles to the point where they more resemble those attributed to invasive forest-associated species.

- 3.8. If no modifications seem possible or warranted, are we ready to recommend abandonment of the indicator? These indicators can be placed in category four.

Not applicable. We do not recommend abandoning Indicator 1.2.4.

- 3.9. If we recommend abandonment, can we identify any new and closely allied indicators that might suit our needs better under climate change? These indicators can be placed in category five.

Not applicable. Indicator 1.2.4, sufficiently modified, will continue to provide a useful SFM signal in the face of climate change.

- 3.10. Have extant climate-change impacts made this indicator more pertinent to SFM (i.e. 2.3 and the mountain pine beetle)? These indicators can be placed in category five or considered for conversion from a supporting to a core indicator (where applicable).

Many of the recent major outbreaks of forest pests that have been attributed to climate change are in fact outbreaks of native species (Williamson et al., 2009). These include the mountain pine beetle outbreak in British Columbia and Alberta (Kurz et al., 2008), the largest ever recorded outbreak of spruce bark beetle (*Dendroctonus rufipennis*) in the Yukon (Berg et al., 2006), and the drothistoma needle blight (*Mycosphaerella pini*) in northwest British Columbia (Woods et al., 2005).

There is not as much evidence of climate-change influencing introduced, invasive species, due in part to the uncertainty and complexity of their relationships with native species and communities, the implications of different land-use activities, and the direct influence of climatic change (Dale et al., 2001). However, laboratory studies of the balsam wooly adelgid (*Adelges piceae*) suggest that elevated temperatures significantly increase mortality of infested fir (*Abies* spp.) trees (Dale et al., 1991).

- 3.11. How should the surviving indicator (the original, modified, or new) be modelled and monitored so that stronger SFM signals may be generated?

The Canadian Food Inspection Agency (CFIA) is responsible for management and quarantines of forest pests and diseases, which is regulated by the Plant Protection Act, and is therefore a source of data for the number of invasive, alien forest-associated species.

The Canadian National Forestry Database and National Forest Inventory (CanFI, 2001; CCFM, 2006b) would likely provide useful sources of spatial data on the area of forest disturbed, especially of native forest pests, if the modified indicator is accepted. However, data constraints would certainly be more pronounced with the modified indicator.

- 3.12. Does this indicator track an entity whose relationship with climate is regionally variable?

There will be regional implications for the influence of climate change on both the original and modified Indicator 1.2.4.

INDICATOR 1.3.1 GENETIC DIVERSITY OF REFORESTATION SEED-LOTS

1. Linkages Assessment

Table 1.1. Indicators influencing Indicator 1.3.1.

Indicator 1.3.1	Influencing Indicators
First order positive	1.3.2
First order negative	None
First order bi-directional	6.4.2 and 6.5.4

Table 1.2. Indicators influenced by Indicator 1.3.1.

Indicator 1.3.1	Influenced Indicators
First order positive	2.1 and 2.5
First order negative	2.3
First order bi-directional	None

- 1.1. Which indicators are influencing and influenced directly (first-order interactions) by the indicator in question? Is the indicator more of a driver of change in other indicators, or being driven by other indicators?

Indicator 1.3.1 is only influenced by three Indicators, which pertain to SFM regulations, standards, and guidelines. It also only influences three other Indicators, all from Criterion 2. As an action indicator, Indicator 1.3.1 is not driven to change by many other indicators, but it is also not a major driver of change.

- 1.2. List the indicators described as ‘relevant indicators under other criteria’ in the 2003 C&I-SFM. Is there any conflict with the interactions described in the matrix?

The only indicator listed as relevant to genetic diversity is Indicator 2.5, as the reforestation stock used in planted cutovers, and the genetic diversity thereof, can be influential on regeneration success.

- 1.3. Are there any overlaps or gaps in the relationship with indicators defined in Eddington and colleague’s (2009) report?

The FFEI Indicator 15 *Genetic Diversity* within the *Biodiversity* category is similar in concept to Element 1.3 *Genetic Diversity* within the C&I framework. However, there is very little similarity to Indicator 1.3.1. Two potential approaches to monitoring that are suggested are assessing species that are considered at-risk due to decline in genetic diversity in British Columbia, and monitoring the application of *in situ* and *ex situ* conservation programs, as is done with Indicator 1.3.2. Eddington and colleagues (2009)

also suggest tracking assisted-migration initiatives for tree species, which will be highly important under climate change.

2. Independent Climate-Change Assessment

- 2.1. Provide in detail, a qualitative description of what are the expected direct effects of climate change on the indicator, using a broad representation from the literature.**

Genetic diversity is a vital component of biological diversity that enables species and populations to better acclimate and adapt to the rapidly changing climate (Gray, 2005). Long-lived species with long generation times, such as trees, are less poised for adaptation to environmental change than shorter-lived species with short generations, such as insects or annual plants (Mátyás, 1997). Climate change in Canada will most likely favour trees with phenotypes and genotypes that are adapted to warmer temperatures (Flemming et al., 2002). However, tree species and forest ecosystems in Canada today evolved in a relatively stable climate over the past millennia, and the rate and magnitude of current environmental change may exceed their rate to adapt, leading to declines in genetic diversity (Gray, 2005).

Close to half of the timber-harvest area in Canada is artificially regenerated (NRCan, 2007). Consequently, the genetic diversity of reforestation seed-lots and corresponding policy of where and how seed is collected from play a major role in the genetic diversity of Canada's operational forests and in climate-change adaptation. Managing genetic resources to be climatically adapted to specific regions is the goal of seed transfer guidelines, which are in place in approximately half of Canada's jurisdictions (McKenney et al., 2009). These seed transfer guidelines have considerable potential to facilitate assisted migration efforts for tree species in order to minimize the impacts of genetic maladaptation of forests to future climates, such as declines in productivity and increased vulnerability to forest pests (Millar et al., 2007).

As with many of the action indicators within the C&I framework, the implications of climate change for the indicator's relevance to SFM emphasize opportunities to facilitate climate-change adaptation. However, because Indicator 1.3.1 is an action indicator that describes the sources and number of parents from which seed is collected, there is additional change in any of the other Indicator traits.

- 2.2. Given expected changes in Canada's climate, describe if and how the indicator's ability to signal progress towards SFM remains unchanged.**

The ability of Indicator 1.3.1 to signal progress towards SFM will remain largely unchanged. This indicator offers a relatively simple measure of genetic diversity of regeneration seed-lots by assessing the number parents used for collecting seed (CCFM, 2006). The rate and magnitude of climate change in Canada may lead to a decline in the genetic diversity of tree species (Gray, 2005). As such, jurisdictions may adjust their seed

transfer guidelines to promote assisted migration of more southerly genetic resources. This has serious implications for the relevance of Indicator 1.3.1, yet the current structure of the Indicator will not reflect this.

- 2.3. If an indicator's ability to signal progress towards SFM will be changed, describe if and how the indicator may become worse or better at signalling SFM progress.

The ability of Indicator 1.3.1 to signal SFM progress will not deteriorate significantly under climate change. However, the described increases in indicator relevance may yield an opportunity to improve the strength of the SFM signal generated by Indicator 1.3.1, which cannot be realized under the Indicator's current design.

3. Integrated Climate-Change Assessment

- 3.1. What are the key determinants of the indicator (i.e. what causes it to change when it does change);

- a) Among other indicators in the C&I framework?
 - **The development and implementation of new forest-management guidelines and standards pertaining to the genetic diversity of seed-lots, and the compliance with them, are determinants of Indicator 1.3.1. These are tracked by Indicators 6.5.4 and 6.4.2.**
- b) Among determinants not within the C&I framework?
 - **As an action indicator, Indicator 1.3.1 is a measure of the implementation of forest-management activities, and is in part determined by forest-management planning and government and company regulations and policy.**

- 3.2. For what other entities is this indicator a key determinant (i.e. when it changes, what other indicators are influenced to change);

- a) Among other indicators in the C&I framework?
 - **The genetic diversity of tree species improves the resistance and resilience of trees to forest insects and pathogens. Therefore, Indicator 1.3.1 is a determinant of Indicator 2.3.**
 - **The suitability of genetic resources to local climatic conditions is influential on both forest regeneration and productivity, and as such is a determinant of Indicators 2.5 and 2.1.**

- **The genetic diversity of reforestation seed-lots is highly important to the few indicators for which it is a determinant, mainly those within Criterion 2. Also, Indicator 1.3.1 may become a vital tool in *ex situ* conservation efforts of native tree species (Indicator 1.3.2) in a changing climate.**

b) Among determinants not within the C&I framework?

- **An external factor that is determined by Indicator 1.3.1 is the actual genetic diversity of tree species and of forest ecosystems. This is external to Element 1.3 because due to the feasibility of measuring of genetic diversity.**

3.3. To what degree can we now, on the basis of extant knowledge, establish how the key determinants interact cumulatively in influencing the indicator?

The most potentially detrimental instance of cumulative effects resulting from the interactions of key determinants is the cumulative maladaptation of tree-species genotypes as they become increasingly unsynchronized with local climates (McKenney et al., 2009). Furthermore, the long generation time and many natural and anthropogenic barriers to tree dispersal and migration will exacerbate these genetic maladaptations under climate change (Spittlehouse, 2005).

3.4. Is the indicator largely unrelated to any other, as described by the linkages assessment and evaluation of key determinants? If so, and the indicator was defined as uninfluenced by climate change in the independent assessment, then it can be placed in category one.

As an action indicator, Indicator 1.3.1 is relatively unrelated to other indicators within the C&I framework. The linkages that were defined in the assessment are highly important to some key aspects of forest ecosystem condition and productivity (i.e. Criterion 2). However, interaction with other indicators in the C&I framework and external determinants do not lessen the ability of Indicator 1.3.1 to signal SFM progress. We can therefore allocate Indicator 1.3.1 to category one, *Uninfluenced Indicators*.

3.5. Do the indirect effects of climate change via the linkages with other indicators influence the indicator's ability to signal SFM, regardless of which category was assigned in the independent climate-change assessment?

The only relevant interaction under climate change is the influence of Indicator 6.5.4 on Indicator 1.3.1. New seed transfer guidelines that incorporate assisted migration of genetic stock that is adapted to predicted future climates would certainly influence the number and location of parents from which seed is collected.

- 3.6. If the indicator's ability to signal SFM progress remains the same under a changing climate, can we conclude no negative influence and leave it unchanged? These indicators can be placed in category two.

The ability of Indicator 1.3.1 to signal SFM progress will remain for the most part unchanged under climate change.

- 3.7. If the indicator's ability to signal SFM progress deteriorates when one assumes a changing climate, then what modifications are possible or warranted to improve its ability sufficiently for it to remain among the C&I-SFM? These indicators can be placed in category three.

Not applicable.

- 3.8. If no modifications seem possible or warranted, are we ready to recommend abandonment of the indicator? These indicators can be placed in category four.

Genetic diversity is one of the key building blocks of biological diversity and a critical component of the environmental, social, and economic benefits we associate with forest biodiversity. As such, Indicator 1.3.1 will remain an asset in monitoring genetic diversity as it relates to SFM, and will not significantly diminish in its ability to do so. However, given the increase in Indicator relevance we may wish to recommend an additional indicator for Element 1.3.

- 3.9. If we recommend abandonment, can we identify any new and closely allied indicators that might suit our needs better under climate change? These indicators can be placed in category five.

Regulating how and where we collect reforestation seed stock in order to minimize the uncoupling of tree genotypes to their environment can be done by updating seed transfer guidelines in Canada's jurisdictions. This is described by McKenney and colleagues (2009) as a pro-active and viable approach to assisted migration.

The threats of climate change to the genetic diversity of forest ecosystems are not fully captured by Element 1.3. While we do not recommend abandonment of Indicator 1.3.1, these potential climate-change impacts and the aforementioned role of assisted migration in conserving genetic diversity in a changing climate may necessitate a new indicator. We therefore propose the *Proportion of Tenured Forest Area with Seed Transfer Guidelines that Account for Climate Change* as a new indicator for the C&I framework.

- 3.10. Have extant climate-change impacts made this indicator more pertinent to SFM (i.e. 2.3 and the mountain pine beetle)? These indicators can be placed in category five or considered for conversion from a supporting to a core indicator (where applicable).

Climate-change impacts on genetic diversity are not nearly as apparent as extent impacts on ecosystem diversity, such as the loss of alpine forest ecosystems at high elevations (Cumming & Burton, 1996). However, changes in forest management policy in response to climate change may also be apt for consideration. As mentioned previously, one of the key mechanisms for climate-change influence on Indicator 1.3.1 is the development and implementation of new seed transfer guidelines and standards, which are in-part captured by Indicator 6.5.4. Recent modifications to seed transfer guidelines in British Columbia to account for both predicted changes in climate and changes experienced over the past century are a prime example of this (O'Neill et al., 2008), and can be considered as an extant issue pertinent to Indicator 1.3.1.

- 3.11. How should the surviving indicator (the original, modified, or new) be modelled and monitored so that stronger SFM signals may be generated?

The current approach to monitoring Indicator 1.3.1 involves a qualitative description of the sources of seed and seedlings used for reforestation in selected jurisdictions, such as British Columbia, Ontario, and Prince Edward Island, in the 2005 status report (CCFM, 2006). This method provides good detail on specific measures of seed-source diversity. However, if this approach is maintained, a stronger SFM signal could possibly be generated by a more inclusive assessment of standards and guidelines of seed collection in all jurisdictions.

- 3.12. Does this indicator track an entity whose relationship with climate is regionally variable?

The regional variability of climate-change influence on Indicator 1.3.1 is more strongly matched to the jurisdictions of Canada and their forest management policies, standards, and guidelines, rather than its terrestrial ecozones.

INDICATOR 1.3.2 STATUS OF IN SITU AND EX SITU CONSERVATION EFFORTS FOR NATIVE TREE SPECIES WITHIN EACH ECOZONE

1. Linkages Assessment

Table 1.1. Indicators influencing Indicator 1.3.2.

Indicator 1.3.2	Influencing Indicators
First order positive	1.1.2, 1.2.4, and 6.4.2
First order negative	2.2, 2.3, 5.3.1, and 5.3.2
First order bi-directional	6.5.4

Table 1.2. Indicators influenced by Indicator 1.3.2.

Indicator 1.3.2	Influenced Indicators
First order positive	1.1.2, 1.2.2, 1.2.3, and 1.3.1
First order negative	1.2.4 and 5.1.5
First order bi-directional	6.5.4

- 1.1. Which indicators are influencing and influenced directly (first-order interactions) by the indicator in question? Is the indicator more of a driver of change in other indicators, or being driven by other indicators?

Indicator 1.3.2 is influenced by eight other indicators and influences seven others from all Criteria except for Criteria 3 and 4. Indicator 1.3.2 is for the most part an equal driver of change and driven to change by other indicators, many of which are both influencing and influenced by it.

- 1.2. List the indicators described as ‘relevant indicators under other criteria’ in the 2003 C&I-SFM. Is there any conflict with the interactions described in the matrix?

There is only one indicator described as relevant to genetic diversity, though it refers far more to Indicator 1.3.1. Indicator 2.5 is influenced by the genetic diversity reforestation stock selected to be used in planted areas.

- 1.3. Are there any overlaps or gaps in the relationship with indicators defined in Eddington and colleague’s (2009) report?

The FFEI Indicator 15 *Genetic Diversity* within the *Biodiversity* category is similar in concept to Element 1.3 *Genetic Diversity* within the C&I framework, and suggests several approaches to monitoring the rather difficult to assess diversity of tree-species genetics. One such approach is tracking the implementation of *in situ* and *ex situ* conservation programs, which of course has significant overlap with Indicator 1.3.2

2. Independent Climate-Change Assessment

- 2.1. Provide in detail, a qualitative description of what are the expected direct effects of climate change on the indicator, using a broad representation from the literature.

Genetic diversity is the total number of unique genetic characteristics within a species and is vital to the maintenance of biological diversity (Groom et al., 2006). Conserving genetic diversity and rare genotypes and alleles within a species or population can be seen as conserving its evolutionary and adaptive potential in response to future stressors and environmental change (Beardmore et al., 2006). Tree species in Canada are faced with a variety of threats, such as changes in land-use and fragmentation, invasive alien species, and unsustainable harvest practices (Beardmore et al., 2006).

Global environmental change poses a serious additional threat to the conservation of native tree species in Canada. Climate change will most likely favour trees with phenotypes and genotypes that are adapted to warmer temperatures (Flemming et al., 2002). However, tree species and forest ecosystems in Canada today evolved in a relatively stable climate over the past millennia, and the rate and magnitude of current environmental change may exceed their rate to adapt, leading to declines in genetic diversity (Gray, 2005). This, in combination with existing stressors on native tree populations, may lead to severe declines or extinction of some species, such as the stressed, genetically depleted populations of Carolinian broadleaved species in southern Ontario (Beardmore et al., 2003). The loss of genetic resources due to regional extirpation or extinction of native tree species is one that for the most part cannot be recovered, a fact that is the driving force behind many different conservation efforts across the country (Mosseler, 1992).

Climate change poses serious threats to the conservation of genetic resources of native tree species (Gray, 2005). The majority of North American tree species are managed *in situ* (Rogers & Ledig, 1996), a strategy that relies on the assumption that historic ranges will remain constant (McCarty, 2001). The foundations of *in situ* conservation share the same assumption of biogeographic stability as the current protected areas policy in Canada (Scott & Lemieux, 2005), both of which are challenged by predicted future changes in climate (see the evaluation of Indicator 1.1.2). The northern and upward migration of tree species resulting from climate change will threaten many of the established, spatially-static systems of conservation (McKenney et al., 2007; Iverson et al., 2008). Efforts such as the establishment of protected areas of for rare trees and shrubs in Prince Edward Island or the identification and conservation of biologically representative areas in wilderness parks in Saskatchewan could be deficient given these predicted impacts (CCFM, 2006).

The development of *ex situ* conservation efforts for native tree species will also be influenced by climate change, but is not as vulnerable as *in situ* efforts, as it does not rely on the biogeographic stability of protected or managed areas. This component of Indicator 1.3.2 is more similar to an action indicator, whose climate-change implications are comparable to those of Indicator 1.3.1 *Genetic Diversity of Reforestation Seedlots*.

- 2.2. Given expected changes in Canada's climate, describe if and how the indicator's ability to signal progress towards SFM remains unchanged.

The ability of Indicator 1.3.2 to signal SFM progress will deteriorate under climate change.

- 2.3. If an indicator's ability to signal progress towards SFM will be changed, describe if and how the indicator may become worse or better at signalling SFM progress.

Indicator 1.3.2 is an action indicator. Therefore, as with Indicator 1.3.1, *ex situ* conservation efforts may increase in relevance and be a tool for native tree-species conservation in the face of climate change (McKenney et al., 2009). Climate change does not degrade the SFM signal of this component of Indicator 1.3.2. However, we must treat the Indicator as a whole, and as such the ability of Indicator 1.3.2 to signal progress towards SFM will deteriorate due to a decline in predictability, responsiveness, and relevance. This is primarily due to the core assumptions of *in situ* conservation efforts.

3. Integrated Climate-Change Assessment

- 3.1. What are the key determinants of the indicator (i.e. what causes it to change when it does change);

- a) Among other indicators in the C&I framework?
- **Habitat loss and alteration are considered the greatest threat to biological diversity, including that of native tree species. Therefore, Indicator 2.2 and 2.3 are determinants of Indicator 1.3.2.**
 - **Competition and herbivory from invasive, alien species are believed to be the second biggest threat to biological diversity, and certainly influence the conservation-status of native tree species. Therefore, Indicator 1.2.4 is a key determinant.**
 - **The genetic diversity of reforestation seedlots, (Indicator 1.3.1) is a determinant of *ex situ* conservation efforts. Conversely, Indicator 1.1.2 is a determinant of *in situ* conservation efforts.**

- b) Among determinants not within the C&I framework?
- **There is a myriad different complex genetic, physiological, phenological, and ecological factors influencing native tree species and their distributions and genetic diversity.**

3.2. For what other entities is this indicator a key determinant (i.e. when it changes, what other indicators are influenced to change);

a) Among other indicators in the C&I framework?

- **Many forest-associated species rely on particular tree species and communities during their life-cycles. Therefore, Indicator 1.3.2 is a determinant of the indicators within Element 1.2.**
- **Indicator 6.5.4 can be influenced by new at-risk designations of native tree species yet it may also be a determinant of new conservation efforts.**
- **Native tree species, populations, or even particular stands and individuals may have strong societal or spiritual value associated with them, which is in part reflected by Indicator 5.1.5.**

b) Among determinants not within the C&I framework?

- **As was previously mentioned, individual tree species may have key and complex roles in forest ecosystems and food webs, which cannot not be entirely reflected in the C&I framework.**

3.3. To what degree can we now, on the basis of extant knowledge, establish how the key determinants interact cumulatively in influencing the indicator?

As with Indicator 1.2.1, climate change is most often predicted to be an additional stressor that will interact cumulatively with existing threats to native tree species. For example, the COSEWIC-designated whitebark pine (*Pinus albicaulis*) in British Columbia and Alberta has recently been assessed as endangered (COSEWIC, 2010). It faces the cumulative stress from the mountain pine beetle (*Dendroctonus ponderosae*) outbreak, white pine blister rust (*Cronartium ribicola*), and fire suppression. These threats, in combination with the likelihood of habitat loss due to climate change, were behind the reasoning of the recent designation as endangered.

3.4. Is the indicator largely unrelated to any other, as described by the linkages assessment and evaluation of key determinants? If so, and the indicator was defined as uninfluenced by climate change in the independent assessment, then it can be placed in category one.

Indicator 1.3.2 is related to several other indicators in the C&I framework and is both directly and indirectly influenced by climate change. We do not recommend assigning it to category one.

- 3.5. Do the indirect effects of climate change via the linkages with other indicators influence the indicator's ability to signal SFM, regardless of which category was assigned in the independent climate-change assessment?

In addition to the direct influence of climate change on Indicator 1.3.2 due to shifts in the ranges of native tree species, there is also a strong potential for indirect climate-change effects. The predicted increases in the frequency and magnitude of extreme weather events, forest fires, insect and disease outbreaks, and climate-induced changes in forest area all have the potential to place increased pressure on existing populations of native tree species (Dale et al., 2001; Williamson et al., 2009; Gray, 2005). Consequently, climate change may indirectly impact indicator 1.3.2 via Indicators 2.2, 2.3, and 3.3.

The development of new forest management guidelines, represented by Indicator 6.5, and new conservation initiatives in response to climate change could be favourable for the conservation of native tree species.

- 3.6. If the indicator's ability to signal SFM progress remains the same under a changing climate, can we conclude no negative influence and leave it unchanged? These indicators can be placed in category two.

Not applicable. The ability of Indicator 1.3.2 to signal SFM progress will deteriorate with climate change.

- 3.7. If the indicator's ability to signal SFM progress deteriorates when one assumes a changing climate, then what modifications are possible or warranted to improve its ability sufficiently for it to remain among the C&I-SFM? These indicators can be placed in category three.

Some of the described conservation efforts, especially *in situ* approaches like protected areas and targeted forest-management strategies, may no longer be viable approaches to native tree-species conservation because of climate change. This poses a threat to the predictability, responsiveness, and relevance of Indicator 1.3.2. However, these conservation efforts that are initiated by federal, provincial, and territorial governments and nongovernmental agencies may adapt to the additional stress of climate change on the genetic resources of native tree species.

Because of the very diverse nature of conservation efforts and differences in their administration, implementation, and success, we can think of no modifications or additional indicators that might deter the weakening of Indicator 1.3.2. However, it is reasonable to assume that many of the *in situ* and especially the *ex situ* conservation efforts will adapt to incorporate the additional threats of climate change. In this case, the current design of Indicator 1.3.2 may remain sufficient to monitor these advancements.

- 3.8. If no modifications seem possible or warranted, are we ready to recommend abandonment of the indicator? These indicators can be placed in category four.

Not applicable. Despite to decline in the ability of Indicator 1.3.2 to signal SFM progress, we do not recommend abandoning it.

- 3.9. If we recommend abandonment, can we identify any new and closely allied indicators that might suit our needs better under climate change? These indicators can be placed in category five.

Not applicable.

- 3.10. Have extant climate-change impacts made this indicator more pertinent to SFM (i.e. 2.3 and the mountain pine beetle)? These indicators can be placed in category five or considered for conversion from a supporting to a core indicator (where applicable).

For an example of extant climate-change impacts on native tree species and their conservation we will again refer to the threats facing whitebark pine described above. Climate change will very likely pose threats to other tree species that are designated by COSEWIC and/or listed under the Canadian Species at Risk Act, such as American chestnut (*Castanea dentata*), butternut (*Juglans cinerea*), cherry birch (*Betula lenta*), and several species of willow (*Salix* spp.), all of which are threatened by habitat loss or introduced biological disturbance agents (Government of Canada, 2009).

- 3.11. How should the surviving indicator (the original, modified, or new) be modelled and monitored so that stronger SFM signals may be generated?

The current approach to monitoring the status of *in situ* and *ex situ* conservation efforts provides detailed descriptions of programs in Canada's jurisdictions, but offers little insight into the status or success of these programs. A brief description of the success, failure, or relevant findings of each of these initiatives would strengthen the SFM signal generated by Indicator 1.3.2.

- 3.12. Does this indicator track an entity whose relationship with climate is regionally variable?

Regional variability in climate-change impacts will certainly influence the type and status of conservation efforts, but does not necessarily influence the current design of Indicator 1.3.2 for monitoring them.

INDICATOR 2.1 TOTAL GROWING STOCK OF BOTH MERCHANTABLE AND NON-MERCHANTABLE TREE SPECIES ON FOREST LAND

1. Linkages Assessment

Table 1.1. Indicators influencing Indicator 2.1.

Indicator 2.1	Influencing Indicators
First order positive	1.3.1, 2.2, 2.5, and 3.1
First order negative	1.2.2, 1.2.3, 1.2.4, 2.3, 2.4, 3.3, 5.3.1, and 5.3.2
First order bi-directional	1.1.1, 1.1.2, and 6.4.2

Table 1.2. Indicators influenced by Indicator 2.1.

Indicator 2.1	Influenced Indicators
First order positive	2.3, 3.3, 4.1.1, and 4.1.2
First order negative	5.3.1 and 5.3.2
First order bi-directional	1.2.1, 1.2.2, and 1.2.3

- 1.1. Which indicators are influencing and influenced directly (first-order interactions) by the indicator in question? Is the indicator more of a driver of change in other indicators, or being driven by other indicators?

Indicator 2.1 is influenced by 15 other indicators directly, from All Criteria except for Criterion 4. It influences nine other indicators, from all Criteria except Criterion 6. Indicator 2.1 is one of the key indicators within the C&I framework, especially for the supply, harvest, and production of timber products, and is both heavily influenced by many indicators in the C&I framework and is a strong driver of change in other indicators.

- 1.2. List the indicators described as ‘relevant indicators under other criteria’ in the 2003 C&I-SFM. Is there any conflict with the interactions described in the matrix?

The condition and productivity of forest ecosystems, including Indicator 2.1, is highly relevant to biological diversity. Indicator 1.1.1 is described as relevant to a forest’s resilience to change and growing stock, while changes in growing stock can be drivers for Indicators 1.2.1, 1.2.2, and 1.2.3.

Soil disturbance can also be detrimental to forest productivity and future growing stock, so Indicators 3.1 and 3.2 are also described as relevant to Indicator 2.1. Total growing stock of managed forests is later described as relevant to social and economic goods and services derived from forest ecosystems, as represented by Criterion 5.

- 1.3. Are there any overlaps or gaps in the relationship with indicators defined in Eddington and colleague’s (2009) report?

Indicator 13 *Ecosystem Productivity* in the *Biodiversity* category of the FFEI indicator set is the closest in design to Indicator 2.1. The effects of climate change on forest-ecosystem productivity will be diverse and complex in nature, especially in British Columbia's varying topography and climate, ranging from elevated growth rates and biomass accumulation due to higher temperatures and longer growing seasons to declining overall productivity caused by more frequent and severe natural disturbances (Eddington et al., 2009; Williamson et al., 2009). FFEI Indicator 13 is a relatively inclusive indicator of ecosystem productivity, but is closest in design to Indicator 2.1, focusing largely on wood volume. Approaches to data collection for Indicator 13 mention the National Forest Inventory as a data source, the same source used in the 2005 assessment of Indicator 2.1 (CCFM, 2006), as well as satellite-based, remote-sensing tools.

2. Independent Climate-Change Assessment

- 2.1. Provide in detail, a qualitative description of what are the expected direct effects of climate change on the indicator, using a broad representation from the literature.

It is widely estimated that climate change will significantly influence the growth and productivity of terrestrial biota, including trees and forest ecosystems (Peng & Apps, 1999; Schimel et al., 2001; Bernier, 2007; Williamson et al., 2009). However, there is a tremendous amount of uncertainty around the effects of climate change on forest productivity (Heimann & Reichstein, 2008), as they will likely be both extremely variable by region, with increases in productivity in high altitudes and latitudes (Chaplin et al., 1995) and decreases in productivity in nutrient- and moisture-limited areas (Friend, 2010). Future forest productivity will also be highly dependent upon changing natural disturbance regimes (Dale et al., 2001).

Unlike many of the detrimental impacts of climate change on forest ecosystems, the changes in climate are frequently predicted to be favourable for the metabolic processes of trees and may lead to increases in forest productivity in many regions (Norby et al., 2005; McMahon et al., 2010). This is because the warming temperatures might increase the metabolic rate of trees and the length of the growing season, leading to more rapid biomass accumulation and a longer period to be metabolically active, respectively (Colombo & Buse, 1998; McMahon et al., 2010).

The elevated concentrations of atmospheric carbon dioxide (CO₂) might also play a role in future forest productivity due to the process of carbon fertilization. Carbon fertilization or enrichment is a complex process, in which trees maintain higher rates of photosynthesis in the elevated atmospheric CO₂ concentrations by lowering stomatal conductance and thus improving water-use efficiency (Farquhar et al., 1980; Friend, 2010). This increase in water-use efficiency minimizes constraints of forest productivity from soil-water availability. There is some debate around the benefits of carbon fertilization for forest productivity, as trees may acclimate to the higher sustained CO₂ concentration, decreasing this initial positive response (Gitay et al., 2001).

Several other key determinants may be highly influential on the cumulative effects of climate change on forest productivity and Indicator 2.1, including the changes to natural disturbance regimes, changes in precipitation rates, especially during the growing season, and the frequency of winter thaw-freeze events (Dale et al., 2001; Williamson et al., 2009).

- 2.2. Given expected changes in Canada's climate, describe if and how the indicator's ability to signal progress towards SFM remains unchanged.

The ability of Indicator 2.1 to signal SFM progress will be altered due to climate change.

- 2.3. If an indicator's ability to signal progress towards SFM will be changed, describe if and how the indicator may become worse or better at signalling SFM progress.

Indicator 2.1 is one of the most fundamental indicators of SFM (CCFM, 2006). The growing stock of merchantable and non-merchantable trees has and will likely continue to be affected by climate change. Given these aforementioned climate-induced changes in forest productivity, Indicator 2.1 may both gain in relevance but decline predictability and measurability. Therefore, the SFM signal generated by Indicator 2.1 may be slightly diminished, not because of how we interpret growing stock and its relation to SFM in a changing climate (i.e. its relevance), but because of how it is often measured and the predictability of these measurements. Wood volume is usually estimated using large remotely-sensed sample areas, typically 1:20,000 aerial photographs, in combination with empirically-based growth and yield functions. This procedure as a benchmark for forecasting future wood volume may no longer be adequate given the predicted uncertain, regionally variable, and species-dependent changes in forest productivity caused by climate change (Linder, 2000).

3. Integrated Climate-Change Assessment

- 3.1. What are the key determinants of the indicator (i.e. what causes it to change when it does change);

- a) Among other indicators in the C&I framework?
- **Ecosystem diversity and forest age and type are key determinants of Indicator 2.1, as represented by Indicators 1.1.1 and 1.1.2.**
 - **Natural disturbance regimes and timber harvests are also major determinants of growing stock, making Indicators 2.3 and 3.3 important determinants. Also reflected in this relationship is the annual of harvest of timber and non-timber forest products, as indicated by 5.3.1 and 5.3.2.**

- **Compliance with forest policy and management guidelines that affect forest productivity are also important determinants, such as Indicators 3.1 and 6.4.2.**
- **The successful regeneration of timber harvest area and deletions or additions of forest area are also determinants of Indicator 2.1, represented by Indicators 2.2 and 2.5.**
- **Forest-dwelling wildlife has an influence over its habitat through competition and herbivory, making Indicators 1.2.2 and 1.2.3 determinants of Indicator 2.1.**

b) Among determinants not within the C&I framework?

- **The growth and productivity of trees and total growing stock of merchantable and non-merchantable trees involve complex processes that are influenced by many different factors. Climate and site conditions are two vital determinants of Indicator 2.1 that are largely external to the C&I framework.**

3.2. For what other entities is this indicator a key determinant (i.e. when it changes, what other indicators are influenced to change);

a) Among other indicators in the C&I framework?

- **The total growing stock of trees in Canada's forests, as tracked by Indicator 2.1, is one of the most basic components of SFM, and has wide ranging influence over the C&I framework. One of the most integral relationships that are tracked by the C&I –SFM is the role of Indicator 2.1 in informing sustainable harvest levels and thus determining Indicators 5.3.1 and 5.3.2.**
- **Indicator 2.1 is the key determinant of Indicators 4.1.1 and 4.1.2.**
- **Indicators within Element 1.2 are also partly determined by Indicator 2.1 because of the relationship of growing stock to habitat conditions. These include Indicators 1.2.1, 1.2.2, and 1.2.3.**

b) Among determinants not within the C&I framework?

- **The role of tree-species growing stock, and hence tree biomass in forest-ecosystem dynamics is central, and Indicator 2.1 has influence on many components not included in the C&I framework. However, the importance of Indicator 2.1 to SFM has led to the representation of many of its key influences on other entities within the CCFM indicator set.**

- 3.3. To what degree can we now, on the basis of extant knowledge, establish how the key determinants interact cumulatively in influencing the indicator?

Many different cumulative effects can be seen from the interaction of determinants on Indicator 2.1 at varying scales. For instance, at the stand level, the cumulative interaction of soil disturbance from previous harvest operations and extant site conditions with the genetic diversity of reforestation seed-lots and the success of natural regeneration might be the most influential on merchantable volume (Brassard & Chen, 2010). Conversely, at the landscape scale the interactions of major changes in land use, such as deforestation for agriculture or development, and natural disturbances may be far more influential on Indicator 2.1. Indicator 2.1 is largely dependent on the interaction of its key determinants.

- 3.4. Is the indicator largely unrelated to any other, as described by the linkages assessment and evaluation of key determinants? If so, and the indicator was defined as uninfluenced by climate change in the independent assessment, then it can be placed in category one.

Indicator 2.1 is highly related to other indicators in the C&I framework and to external determinants of change. It should not be assigned to category one.

- 3.5. Do the indirect effects of climate change via the linkages with other indicators influence the indicator's ability to signal SFM, regardless of which category was assigned in the independent climate-change assessment?

Indicator 2.1 is highly susceptible to direct climate-change influence, as described in the independent climate-change assessment. The main vector for indirect climate-change influence is through changes in natural disturbance regimes and Indicator 2.3. Despite the influence of increased temperatures and CO₂ concentrations on forest productivity, it is widely speculated that the natural disturbances will be the ultimate determinant of landscape-scale forest productivity and therefore of Indicator 2.1 (Dale et al., 2001; Schimel et al., 2001; Scheller & Mladenoff, 2005).

- 3.6. If the indicator's ability to signal SFM progress remains the same under a changing climate, can we conclude no negative influence and leave it unchanged? These indicators can be placed in category two.

The ability of Indicator 2.1 to signal SFM progress may be slightly diminished by the decline in indicator predictability and measurability. As such, it should not be placed in category two.

- 3.7. If the indicator's ability to signal SFM progress deteriorates when one assumes a changing climate, then what modifications are possible or warranted to improve its ability

sufficiently for it to remain among the C&I-SFM? These indicators can be placed in category three.

Wood volume data from Canada's National Forest Inventory are estimated using statistical correlations of remotely sensed, aerial photograph samples from small, ground-based sample areas (CanFI, 2004). Traditional, empirically-based growth and yield models use similar strategies, based on sample-plot data. This reliance on pre-established relationships and processes that are based on historical climates may invalidate these approaches in a changing and unstable climate (O'Neill et al., 2008; Williamson et al., 2009). Furthermore, spatial variation in the response of forest productivity to climate change also lessens the predictability of the Indicator. These issues cannot be mitigated solely by modifications to Indicator 2.1, as they require developments in modelling techniques that no longer rely on the core assumption that historical stand development will determine future growth rates (Williamson et al., 2009).

- 3.8. If no modifications seem possible or warranted, are we ready to recommend abandonment of the indicator? These indicators can be placed in category four.

Not applicable. We do not recommend abandoning Indicator 2.1.

- 3.9. If we recommend abandonment, can we identify any new and closely allied indicators that might suit our needs better under climate change? These indicators can be placed in category five.

While we do not recommend the abandonment of Indicator 2.1, we do recommend the creation of a new indicator under Criterion 2. Given the importance of temperature change, as well as other temperature related metrics like growing degree days, on tree growth performance and forest productivity, we recommend *Average, Minimum, and Maximum Temperature* as a new indicator.

- 3.10. Have extant climate-change impacts made this indicator more pertinent to SFM (i.e. 2.3 and the mountain pine beetle)? These indicators can be placed in category five or considered for conversion from a supporting to a core indicator (where applicable).

Lengthening of growing seasons, and changes in forest productivity have already been observed in Canada's forests (Braswell & Schimel, 1997; Zhou et al., 2001; Bunn & Goetz, 2006). Zhang and colleague's (2008) study illustrates an extant climate-change effects on forest productivity in northern Canada. An average increase in net primary productivity (NPP) was observed from 1983 to 2005 in high-latitude boreal-arctic forests in North America. Moreover, there were major NPP disruptions caused by drought. These drought-induced declines in NPP may become more frequent and influential as the temperature and precipitation regimes continue to change (Zhang et al., 2008).

3.11. How should the surviving indicator (the original, modified, or new) be modelled and monitored so that stronger SFM signals may be generated?

Indicator 2.1 is another indicator whose data are sourced from Canada's National Forest Inventory, which is a compilation of existing inventories from the provincial and territorial jurisdictions (CanFI, 2001). The approach to estimating wood volumes used by the National Forest Inventory, and of course by many of the provincial and territorial natural resource agencies, relies on core assumptions of climate stability that may be invalidated in the coming years. As mentioned above, this is a key driver for the likely decline in the ability of Indicator 2.1 to signal SFM progress.

3.12. Does this indicator track an entity whose relationship with climate is regionally variable?

The influence of climate change on Indicator 2.1 will be highly variably by region.

INDICATOR 2.2 ADDITIONS AND DELETIONS OF FOREST AREA, BY CAUSE

1. Linkages Assessment

Table 1.1. Indicators influencing Indicator 2.2.

Indicator 2.2	Influencing Indicators
First order positive	2.5 and 3.2
First order negative	1.2.4 and 6.4.2
First order bi-directional	6.5.4

Table 1.2. Indicators influenced by Indicator 2.2

Indicator 2.2	Influenced Indicators
First order positive	1.2.2, 1.2.3, 2.1, 2.3, 2.4, 3.3, 4.1.1, 4.1.2, 5.1.5, and 6.1.2
First order negative	1.2.1, 1.3.2, 5.3.1, and 5.3.2
First order bi-directional	1.1.1, 1.2.1, 1.2.4, and 6.5.4

- 1.1. Which indicators are influencing and influenced directly (first-order interactions) by the indicator in question? Is the indicator more of a driver of change in other indicators, or being driven by other indicators?

Indicator 2.2 is influenced by five other indicators, all of which refer to some aspect of forest management except for Indicator 1.2.4. It influences 18 other indicators from all Criteria, making it one of the more influential indicators within the C&I framework. Indicator 2.2 also influences all indicators within Criterion 1, except for Indicator 1.3.1. Indicator 2.2 is much more of a driver of change in other indicators than it is influenced by them.

- 1.2. List the indicators described as ‘relevant indicators under other criteria’ in the 2003 C&I-SFM. Is there any conflict with the interactions described in the matrix?

Indicator 2.2 is substantially relevant to Criterion 1. Indicators 1.1.1, 1.2.1, 1.2.2, and 1.2.3 are all components of biodiversity that will be affected by changes in forest area. The loss of forest area on productive soil is also deemed relevant to the conservation of soil and water resources, inclusive to Criterion, and the carbon storage of forests, represented by Indicators 4.1.1 and 4.1.2.

- 1.3. Are there any overlaps or gaps in the relationship with indicators defined in Eddington and colleague’s (2009) report?

There is no indicator within the FFEI indicator set that is directly matched to Indicator 2.2. However, there may be slight overlap with Indicators 12 *Ecosystem Distribution and*

***Composition and 16 Ecosystem Connectivity* within the *Biodiversity* category. Indicator 12 is more concerned with changes in species and ecosystem distribution due to climate change, but would therefore also address additions and deletions to forest area in high-altitude, montane treelines and dry, moisture-limited ecosystems in the southern interior of the Province. Indicator 16 addresses similar concepts as those pertaining to Indicator 2.2, such as habitat fragmentation and land-use patterns, which will be important for climate-induced species migrations.**

2. Independent Climate-Change Assessment

- 2.1. Provide in detail, a qualitative description of what are the expected direct effects of climate change on the indicator, using a broad representation from the literature.

The area of deforestation and afforestation in Canada were the variables measured in the monitoring Indicator 2.2 for the 2005 C&I-SFM status report (CCFM, 2006). Climate-change mitigation and the large-scale funding of new research under the auspices of such initiatives as Canada's Climate Change Action Fund have been the driver of indirect climate-change influence on Indicator 2.2 (CCAF, 2003; McKenney et al., 2006). This is due primarily to the development of afforestation initiatives, like the Forest 2020 Plantation Development and Assessment initiative (Dominy et al., 2010), which are a source of additions to the forest area in Canada.

Substantial emphasis has been placed on role of deforestation, especially tropical deforestation, in contributing to climate change (IPCC, 2007). However, there is the potential for climate change to also cause gains and losses of forest area in Canada, thereby influencing Indicator 2.2 directly. This is because of changes in temperature and the rate and seasonal variability of precipitation in the climatic extremes of Canada (Williamson et al., 2009). Treeline advance in areas characterized by historically low temperatures like high-altitude forest ecosystems and the boreal-tundra ecotone is believed to be a significant source of forest change in the future (Aitken et al., 2008; Williamson et al., 2009). In warmer regions of Canada where forests are typically limited by moisture, such as the western Canadian interior and the aspen parklands that characterize it, declines in growing-season precipitation are predicted to cause significant dieback and losses of forest area (Hogg et al., 2008).

Standard definitions for deforestation and afforestation usually refer only to direct human activities causing land-use change (UNFCCC, 2001). However, Indicator 2.2, in tandem with Indicator 1.1.1, will need to track additions and deletions of forest area caused by climate change as well.

- 2.2. Given expected changes in Canada's climate, describe if and how the indicator's ability to signal progress towards SFM remains unchanged.

Indicator 2.2 is a critical indicator, as it tracks highly influential determinants of forest change and has major implications for biodiversity. Climate change may directly influence forest area through species migration and dieback and indirectly through new afforestation and carbon sequestration policies. Both of these will increase the relevance of Indicator 2.2 to SFM, while the former will diminish indicator predictability. However, because there are no major declines in relevance or responsiveness of the Indicator, we feel that the SFM signal generated by Indicator 2.2 will not be significantly reduced. In fact, the proliferation of remote-sensing technologies may improve the feasibility of monitoring Indicator 2.2 in the future.

2.3. If an indicator's ability to signal progress towards SFM will be changed, describe if and how the indicator may become worse or better at signalling SFM progress.

The ability of Indicator 2.2 to signal SFM progress will not be overly reduced by climate change.

3. Integrated Climate-Change Assessment

3.1. What are the key determinants of the indicator (i.e. what causes it to change when it does change);

a) Among other indicators in the C&I framework?

- **Aspects of forest management that may cause deforestation can be reflected by two relationships within the C&I framework. Unsuccessful regeneration of timber harvest area (Indicator 2.5) may, in extreme cases or on sensitive sites, lead to deletions of forest area, as will permanent access-road construction and lack of compliance to sustainable forest management laws, standards, and guidelines , tracked by Indicators 3.2 and 6.4.2.**
- **Competition and herbivory from invasive, exotic species, especially plant species, can restrict natural regeneration, as well as reforestation and afforestation efforts. Therefore, Indicator 1.2.4 is a determinant of Indicator 2.2.**

b) Among determinants not within the C&I framework?

- **The primary driver of Indicator 2.2 is anthropogenic influence on forest area. On one hand, the expansion of land-use practices like agriculture and urbanization since European colonization have been a major source of deforestation. Conversely, afforestation initiatives like the 50 Million Tree Program in southern Ontario, a Trees Ontario and Ontario Ministry of Natural Resources partnered initiative are**

becoming a mainstay of climate-change mitigation efforts. However, forces external to the forest sector are the major sources of deforestation (NRCan, 2008).

- **There are some forms of natural disturbance external to the framework that can cause deletions of forest area, such as extreme flooding, droughts, and mass movements, which are therefore determinants of Indicator 2.2.**

3.2. For what other entities is this indicator a key determinant (i.e. when it changes, what other indicators are influenced to change);

a) Among other indicators in the C&I framework?

- **Indicator 2.2 is one of the principal drivers of change in Indicators 1.1.1 and 1.1.2. This is a cardinal relationship, as loss of habitat is seen as the greatest threat to biodiversity in Canada (COSEWIC, 2004; CCFM, 2006).**
- **Several other key forest attributes monitored by the CCFM indicator set are influenced and partly determined by Indicator 2.2, such as Indicators 2.1, 4.1.1, and 4.1.2.**
- **More specific threats to biodiversity from loss of habitat are the influence of Indicator 2.2 on Indicators 1.2.1, 1.2.2, and 1.2.3. Indicator 2.2 will also influence genetic diversity and Indicator 1.3.2.**
- **Several of the Indicators that are incidentally determined by Indicator 2.2 are so simply because of the physical presence or absence of forest area. For example, more forest area means more natural disturbances, making Indicator 2.2 a determinant of Indicators 2.3 and 3.3.**
- **Deforestation and afforestation may also influence the sustainable harvest levels of forest products, as indicated by 5.3.1 and 5.3.2.**

b) Among determinants not within the C&I framework?

- **Indicator 2.2 is such a major driver of forest change in Canada that the majority of its key influences on SFM are adequately represented by linkages within the C&I framework. However, there are certainly many additional subtle and complex ecological, economic, and social repercussions of afforestation and deforestation.**

3.3. To what degree can we now, on the basis of extant knowledge, establish how the key determinants interact cumulatively in influencing the indicator?

The cumulative effects of unsustainable forestry practices or failure to comply with SFM standards, unsuccessful regeneration of timber harvest areas, and colonization by invasive plant species is one of several possible interactions that could lead to deforestation of operational forest land. However, deforestation is most often caused by major changes in land use (NRCan, 2008), and is usually the result of a single action, like land-clearing for agriculture or urbanization, as opposed to a cumulative interaction of activities.

- 3.4. Is the indicator largely unrelated to any other, as described by the linkages assessment and evaluation of key determinants? If so, and the indicator was defined as uninfluenced by climate change in the independent assessment, then it can be placed in category one.

Indicator 2.1 is highly related to other indicators in the C&I framework and to external determinants of change, and is particularly influential on other indicators. We do not recommend assignment to category one.

- 3.5. Do the indirect effects of climate change via the linkages with other indicators influence the indicator's ability to signal SFM, regardless of which category was assigned in the independent climate-change assessment?

The development and implementation of provincial, national, and international policies on climate-change mitigation have had significant influence over Indicator 2.2. Afforestation as a tool for carbon sequestration and climate-change mitigation has gained popularity since the Kyoto Protocol entered into force in 2005 (van Kooten et al., 1999). One of the major tools proposed for emissions reductions under the Protocol was the establishment of forests on previously non-forested land so they may act as carbon sinks, using the now widely known strategy of afforestation (White & Kurz, 2003). Plantations of intensely managed, fast-growing trees, such as hybrid poplar, on abandoned agricultural lands are an example of practiced afforestation strategies (Dominy et al., 2010). This indirect climate-change influence increases the relevance of Indicator 2.2, but has no negative consequence for its ability to signal SFM progress.

- 3.6. If the indicator's ability to signal SFM progress remains the same under a changing climate, can we conclude no negative influence and leave it unchanged? These indicators can be placed in category two.

The ability of Indicator 2.2 to signal our progress towards SFM will be not decline to the point that modification is necessary. This Indicator can therefore be assigned to category two, *Unmodified Indicators*.

- 3.7. If the indicator's ability to signal SFM progress deteriorates when one assumes a changing climate, then what modifications are possible or warranted to improve its ability

sufficiently for it to remain among the C&I-SFM? These indicators can be placed in category three.

Not applicable.

- 3.8. If no modifications seem possible or warranted, are we ready to recommend abandonment of the indicator? These indicators can be placed in category four.

Not applicable.

- 3.9. If we recommend abandonment, can we identify any new and closely allied indicators that might suit our needs better under climate change? These indicators can be placed in category five.

Not applicable.

- 3.10. Have extant climate-change impacts made this indicator more pertinent to SFM (i.e. 2.3 and the mountain pine beetle)? These indicators can be placed in category five or considered for conversion from a supporting to a core indicator (where applicable).

Danby and Hik (2007) studied twentieth-century trends in the subarctic treeline in the Yukon, and found both treeline advances and increases in density of white spruce (*Picea glauca*) and willow (*Salix* spp.) in response to the recent climate-warming. Conversely, aspen dieback has been observed in the southern boreal forest and aspen parkland of western Canada, which was attributed to recent droughts, insect defoliation, and thaw-freeze events caused by climatic change (Frey et al., 2004; Hogg et al., 2008).

Extant examples of afforestation that were catalyzed by global environmental change have also occurred in Canada. For instance, the Government of Canada appointed over one billion dollars for the implementation of a Canadian Climate Change Plan. As part of this, the Canadian Forest Service implemented the Forest 2020 Plantation Demonstration and Assessment (F2020) program (Dominy et al., 2010). The F2020 established several plantation trials of fast-growing, hybrid poplar on previously un-forested land to analyze the feasibility of afforestation for carbon offsetting and as an alternative source for wood fibre (Dominy et al., 2010).

- 3.11. How should the surviving indicator (the original, modified, or new) be modelled and monitored so that stronger SFM signals may be generated?

The monitoring and assessment of deforestation rates in Canada is a substantial and difficult endeavour (Leckie et al., 2002). Full assessment of deforestation rates requires satellite-based observations, land-use records, and field surveys, like those of the plot-based National Forest Inventory (NRCan, 2008). The most recent C&I-SFM assessment in 2005

relied on an independent report prepared by ESSA Technologies (Robinson et al., 1999). New sources have become available since then, such as Environment Canada's (2010) National Inventory Report. Remote sensing is also becoming an increasingly important tool for monitoring deforestation (Leckie et al., 2002), and will likely be vital in assessing climate-induced changes in forest area. Afforestation initiatives are slightly easier to monitor, as they are action-driven and typically well documented by the overseeing governing body (Hall et al., 2004; Dominy et al., 2010).

As was alluded to earlier, clear and explicit definition is highly important for this indicator. We would also like to suggest that urban forests be included in this definition and additions and deletions to the urban canopy be tracked by this Indicator. More than three quarters of Canada's population now live in cities, so urban forest dynamics are what directly affect the majority of Canadians.

3.12. Does this indicator track an entity whose relationship with climate is regionally variable?

The effects of climate change on Indicator 2.2 will be regionally variable, both across the different climate regimes of terrestrial ecozones and different regulatory environments of Canada's jurisdictions.

INDICATOR 2.3 AREA OF FOREST DISTURBED BY FIRE, INSECTS, DISEASE AND TIMBER HARVEST

1. Linkages Assessment

Table 1.1. Indicators influencing Indicator 2.3.

Indicator 2.3	Influencing Indicators
First order positive	1.2.4, 2.1, 2.2, 2.4, 2.5, and 5.3.1
First order negative	1.3.1
First order bi-directional	1.1.1, 1.1.2, 5.2.1, and 6.5.4

Table 1.2. Indicators influenced by Indicator 2.3.

Indicator 2.3	Influenced Indicators
First order positive	1.2.1, 2.5, 3.3, and 5.1.1
First order negative	1.2.2, 1.2.3, 1.3.2, 2.1, 4.1.1, and 4.1.2
First order bi-directional	1.1.1, 1.1.2, 5.3.1, 5.3.2, and 6.5.4

- 1.1. Which indicators are influencing and influenced directly (first-order interactions) by the indicator in question? Is the indicator more of a driver of change in other indicators, or being driven by other indicators?

Indicator 2.3 is influenced by 11 other indicators directly, the vast majority of which are from Criteria 1 and 2. It influences 15 other indicators with first-order interaction, from all Criteria, though the majority is from Criterion 1. Indicator 2.3 is a major driver of change for indicators within the C&I framework, but is also influenced by many different indicators.

- 1.2. List the indicators described as ‘relevant indicators under other criteria’ in the 2003 C&I-SFM. Is there any conflict with the interactions described in the matrix?

All of Criterion 2 is described as relevant to biological diversity. Natural disturbance regimes and timber harvests are highly influential Indicators 1.2.1, 1.2.2, and 1.2.3. They are also a major driver of forest-ecosystem diversity and Indicator 1.1.1. Indicator 2.3 plays a major role in the carbon cycle of forests, and is relevant to Indicators 4.1.1 and 4.1.2. Finally, Indicator 2.3 is mentioned as relevant to the sustainability of benefits from forests and Criterion 5.

- 1.3. Are there any overlaps or gaps in the relationship with indicators defined in Eddington and colleague’s (2009) report?

The FFEI indicator set describes four indicators within the *Natural Disturbances* category: Indicators 8 *Insects and Diseases*, 9 *Wind Throw*, 10 *Fire*, and 11 *Mass Movements*. All of these natural disturbances are predicted to increase in frequency and severity, so it will

therefore be important to monitor both the level of natural disturbance on forests and rangeland and early warning signs so that preventative measures might be implemented (Eddington et al., 2009). Indicator 2.3 is obviously closely related to this entire category, but does not incorporate wind or mass-movement disturbances. Conversely, indicators in the FFEI *Natural Disturbances* category do not address the extent of forest disturbance from timber harvest operations.

2. Independent Climate-Change Assessment

2.1. Provide in detail, a qualitative description of what are the expected direct effects of climate change on the indicator, using a broad representation from the literature.

Increases and variation in temperature and precipitation, along with more frequent and severe weather events, are all symptoms of the changing climate, and are expected to dramatically alter natural disturbance regimes within forest ecosystems (IPCC, 2007). Natural disturbance events like wildfire, insect and disease outbreaks, windstorms and hurricanes, and droughts are all expected to increase in frequency and magnitude, which will have major consequences for forest ecosystem dynamics (Dale et al., 2001; Williamson et al., 2009).

The predicted increase in frequency of intense storms, such as extreme precipitation events, hurricanes, tornados, and catastrophic downbursts, will mean more forest disturbance due to windthrow, especially in managed forests where wind-sensitive, sharp forest edges are far more commonplace (Peterson, 2000; Harper et al., 2004; Williamson et al., 2009). Drought is another forest disturbance that will likely become more significant in Canada's drier interior regions and prairie provinces (Hogg & Bernier, 2006).

The area of forest disturbed by insects in Canada is by far greater than that by all other disturbance agents (CCFM, 2006). Forest insects and pathogens are natural components of forest ecology, often with cyclical population fluctuations or outbreaks, which are limited by climate (Fleming & Candau, 1998; Fleming, 2000). The predicted changes in climate and subsequent shifting of species' ranges are expected to cause longer, more severe, and more frequent outbreaks (Carroll, 2006; Gray, 2008). Fire is another major forest-disturbance agent in Canada. It is predicted that the anticipated temperature increases will lead to more area disturbed by fire, especially in western and central Canada (Flannigan et al., 2009).

A key issue surrounding the effects of climate change on natural disturbance regimes is the high level of uncertainty, as well as the regional variability of these impacts (Williamson et al., 2009). Not only is the future climate, and its effects on natural disturbance regimes and the subsequent forest response highly uncertain, but natural disturbance regimes are also highly interrelated, and there could be unpredictable future interactions and feedbacks of disturbance events.

- 2.2. Given expected changes in Canada's climate, describe if and how the indicator's ability to signal progress towards SFM remains unchanged.

The ability of Indicator 2.3 to signal SFM progress will be altered due to climate change.

- 2.3. If an indicator's ability to signal progress towards SFM will be changed, describe if and how the indicator may become worse or better at signalling SFM progress.

Indicator 2.3 will undoubtedly change in its ability to signal progress towards SFM. First and foremost, Indicator 2.3 will greatly increase in its relevance to SFM because of the more frequent and severe natural disturbance events. Indicator 2.3 is also major driving force within the C&I framework, so this increase in indicator relevance by may also emphasize the influence of the Indicator on those that it interacts with, such as Indicators 1.1.1 and 2.1. There will also be a decline in the predictability of the Indicator, as there is with nearly all biophysical state indicators.

3. Integrated Climate-Change Assessment

- 3.1. What are the key determinants of the indicator (i.e. what causes it to change when it does change);

- a) Among other indicators in the C&I framework?
- **The forest age and cover type, and thus forest-ecosystem diversity, are key determinants of Indicator 2.3, as represented by Indicators 1.1.1 and 1.1.2. Forest structure and composition are highly influential on both natural disturbance dynamics and the likelihood of timber harvest. Genetic diversity is also influential on the vulnerability to forest insects and pathogens, making Indicator 1.3.1 a determinant.**
 - **Indicator 2.1 is a major controlling factor for the area of timber harvest.**
 - **Indicator 2.2 is a determinant of Indicator 2.3, not only because of the complex relationship between forest fragmentation and natural disturbances, but also simply for the fact that more or less forest area means a change in the area that is susceptible to disturbance.**
 - **Invasive, alien species are not explicitly included in the assessment of Indicator 2.3. However, forests disturbed by invasive forest insects or pathogens will be more vulnerable to other forms of natural disturbance, making Indicator 1.2.4 a partial determinant.**
 - **The type of timber tenure agreements and the area of tenured forest, represented by Indicator 5.2.1 is a key determinant of the timber harvest component of Indicator**

2.3, as is Indicator 6.5.4, which can also influence forest practices and the area of timber harvest.

b) Among determinants not within the C&I framework?

- **As with many of the biophysical indicators, both regional and local climate variations and site conditions are key determinants that are external to the C&I framework. The frequency and severity of natural disturbances are closely related to climate, either directly through major storm events, or indirectly through high over-wintering survival of bark beetles. Variation in site conditions, like soil depth and drainage, are also determinants of vulnerability to natural disturbance.**

3.2. For what other entities is this indicator a key determinant (i.e. when it changes, what other indicators are influenced to change);

a) Among other indicators in the C&I framework?

- **Indicator 2.3 is highly influenced by Indicators 1.1.1 and 1.1.2, as mentioned above. However, it is also a key determinant for these Indicators, as natural disturbance regimes and timber harvests are considerable drivers of ecosystems diversity.**
- **The timber harvest component of Indicator 2.3 is a determinant of Indicator 5.3.1. Moreover, the area of forest disturbed by any form of disturbance will also influence Indicator 5.3.2.**
- **The frequency and type of disturbance events are an important determinant of Indicator 2.1, and subsequently of Indicators 4.1.1 and 4.1.2.**
- **Indicator 2.3 is one of the main determinants of forest habitat diversity. Therefore, it is a determinant for Indicators 1.2.1, 1.2.2, and 1.2.3.**
- **The area of forest disturbed is a key determinant of Indicator 6.5.4 in several fashions. One example might be new habitat conservation standards in response to the designation of a forest-associated species by COSEWIC, such as woodland caribou (*Rangifer tarandus caribou*), because it is heavily influenced by forest management activities.**

b) Among determinants not within the C&I framework?

- **Natural disturbance regimes play a major role in forest composition, structure, and regional diversity, and are an integral component of forest-ecosystem dynamics (Pickett & White, 1985). There are many processes and entities of forest ecosystems that will naturally be external the CCFM indicator set, ranging from such diverse**

attributes as understory plant diversity to the availability of fire-dependent berry crops to traditional land-users.

- 3.3. To what degree can we now, on the basis of extant knowledge, establish how the key determinants interact cumulatively in influencing the indicator?

Natural disturbances are highly interrelated, and closely linked with timber harvests. One form of natural disturbance invariably causes a greater vulnerability to additional forms of disturbance (Frelich, 2002). Cumulative influences on forest disturbance have also become a more recognized because of the growing popularity of natural-disturbance emulation in forest management practices as a tool for maintaining biodiversity and natural variability (Attiwill, 1994; Bergeron et al., 2006; Buddle, et al., 2006). For example, basing even-aged forest management in Quebec's boreal forest in an attempt to match large-scale, stand-replacing fires is believed to lead to a greater cumulative influence of harvesting and wildfire on forest structure, because this form of management is not sufficient for fire-harvesting substitution (Bergeron et al., 2006).

- 3.4. Is the indicator largely unrelated to any other, as described by the linkages assessment and evaluation of key determinants? If so, and the indicator was defined as uninfluenced by climate change in the independent assessment, then it can be placed in category one.

Indicator 2.3 is highly related to other indicators in the C&I framework and to external determinants of change, and is a powerful driver of forest-ecosystem change. It should not be assigned to category one.

- 3.5. Do the indirect effects of climate change via the linkages with other indicators influence the indicator's ability to signal SFM, regardless of which category was assigned in the independent climate-change assessment?

The chief source of climate-change influence on Indicator 2.3 is through direct changes in the frequency and severity of natural disturbance events (Dale et al., 2001). However, climate change may also indirectly influence the area of forest disturbed by timber harvest, in response to other direct climate-change impacts. For example, there will presumably be an increased necessity for salvage logging operations in response to more frequent insect outbreaks, windstorms, and wildfires (Spittlehouse, 2005; Lindenmayer & Noss, 2007).

- 3.6. If the indicator's ability to signal SFM progress remains the same under a changing climate, can we conclude no negative influence and leave it unchanged? These indicators can be placed in category two.

The ability of Indicator 2.1 to signal SFM progress may be slightly diminished by the decline in its predictability. Moreover, the current indicator structure may not be

sufficient to capture the increase in relevance that is predicted to result from climate change. As such, it should not be placed in category two.

- 3.7. If the indicator's ability to signal SFM progress deteriorates when one assumes a changing climate, then what modifications are possible or warranted to improve its ability sufficiently for it to remain among the C&I-SFM? These indicators can be placed in category three.

The goal of Indicator 2.3 is to assess the total extent of forest disturbance in order to monitor its influence on the condition and productivity of forest ecosystems (CCFM, 2003). We see no possible modifications to the Indicator that could minimize the decline of its predictability. However, it may be possible to modify it in response to the increases in indicator relevance. We therefore recommend incorporating the other major forms of natural disturbance that will be influenced by climate change into Indicator 2.3, and propose *Area of Forest Disturbed, by Cause* as the modified indicator.

A key goal of monitoring Indicator 2.3 is to assess whether natural disturbances are within an acceptable range of natural variability (CCFM, 2006). Climate change will most likely invalidate this range of natural variability, which is based on a historical and stable climate (Millar et al., 2007). This additional issue posed by climate change will not necessitate further indicator modification, but it does require that we realign the goals associated with Indicator 2.3.

- 3.8. If no modifications seem possible or warranted, are we ready to recommend abandonment of the indicator? These indicators can be placed in category four.

Not applicable. We do not recommend abandoning Indicator 2.3.

- 3.9. If we recommend abandonment, can we identify any new and closely allied indicators that might suit our needs better under climate change? These indicators can be placed in category five.

Not applicable.

- 3.10. Have extant climate-change impacts made this indicator more pertinent to SFM (i.e. 2.3 and the mountain pine beetle)? These indicators can be placed in category five or considered for conversion from a supporting to a core indicator (where applicable).

For an extant example of climate-change impacts relating to Indicator 2.3 we will discuss the well-known mountain pine beetle (*Dendroctonus ponderosae*) outbreak in western Canada. The pine beetle is an endemic species whose host species include lodgepole pine (*Pinus contorta*), ponderosa pine (*Pinus ponderosa*), and jack pine (*Pinus banksiana*), and

has historically had periodic outbreaks whenever conditions were favourable (Carroll et al., 2004). The recent outbreak is the most widespread and severe ever recorded, and is thought to have killed a total of 675 million cubic metres of timber in British Columbia as of 2010, and has now spread into northwestern Alberta (Kurz et al., 2008; BC Ministry of Forests, Mines and Lands, 2010). The main drivers for this outbreak were vast areas of mature lodgepole pine resulting from past management practices and consecutive abnormally warm winters (Carroll et al., 2004; Williamson et al., 2009). Moreover, there were changes in the area of forest disturbed by timber harvest in response to this outbreak. For example, in the Vanderhoof Forest District in British Columbia, allowable annual cut was increased from approximately 2 million cubic metres to 6.5 million cubic metres in an attempt to salvage the beetle-infested pine (Pederson, 2004).

- 3.11. How should the surviving indicator (the original, modified, or new) be modelled and monitored so that stronger SFM signals may be generated?

The primary source of data on the spatial extent of forest disturbance from insects, fires, and timber harvest/silviculture is the National Forestry Database, which is a database of national forestry statistics created by the CCFM (CCFM, 2010). Most data come from provincial and territorial natural resource agencies and are compiled by the CFS. This will likely remain the chief data source for future assessments under climate change.

Several initiatives for monitoring SFM in a changing climate have teased out individual sources of forest disturbance as indicators (Eddington et al., 2009; Seidl et al., 2010). Given that the C&I-SFM is a national initiative, and also the sheer scale of Canada's forests, we do not feel that it is necessary to create individual indicators for each form of natural disturbance. Furthermore, in the CCFM 2005 status report for the assessment of Indicator 2.3, area of forest disturbed by fire, spruce budworm, forest tent caterpillar, mountain pine beetle, and clear-cut harvests and selection harvests were individually measured (CCFM, 2006). The difference between the previously mentioned initiatives being that are all aligned to the same SFM goal under one indicator.

Having directional goals associated with Indicators is an important aspect of monitoring progress towards SFM (Duinker, 2001). As of the 2005 C&I-SFM assessment, there were several jurisdictions in the midst of defining acceptable natural ranges of variability for natural disturbances in order to define appropriate goals (CCFM, 2006). This is certainly a valuable process, but many of the core assumptions of 'natural' ranges of variability are challenged by global environmental change, and will need to be addressed by provincial and federal natural resources agencies.

- 3.12. Does this indicator track an entity whose relationship with climate is regionally variable?

The influence of climate change on Indicator 2.3 will be highly variable across Canada's terrestrial ecozones.

INDICATOR 2.4 AREA OF FOREST WITH IMPAIRED FUNCTION DUE TO OZONE AND ACID RAIN

1. Linkages Assessment

Table 1.1. Indicators influencing Indicator 2.4.

Indicator 2.4	Influencing Indicators
First order positive	2.2 and 4.1.4
First order negative	None
First order bi-directional	None

Table 1.2. Indicators influenced by indicator 2.4.

Indicator 2.4	Influenced Indicators
First order positive	1.2.4 and 2.3
First order negative	1.2.2, 1.2.3, 2.1, 2.5, 4.1.1, 4.1.2, and 5.1.5
First order bi-directional	1.1.1 and 1.1.2

- 1.1. Which indicators are influencing and influenced directly (first-order interactions) by the indicator in question? Is the indicator more of a driver of change in other indicators, or being driven by other indicators?

Indicator 2.4 is only directly influenced by two other Indicators, 2.2 and 4.1.4. However, it influences 11 other indicators, primarily biophysical indicators from Criteria 1, 2, and 4, with the exception of Indicator 5.1.5. Indicator 2.4 is primarily a driver of change in other indicators only.

- 1.2. List the indicators described as ‘relevant indicators under other criteria’ in the 2003 C&I-SFM. Is there any conflict with the interactions described in the matrix?

The condition and productivity of forest ecosystems, and the effects thereupon tracked by Indicator 2.4, are described as highly relevant to Criterion 1, especially Indicators 1.1.1, 1.2.1, 1.2.2, and 1.2.3. Ecological disturbance from ozone and acid rain has major implications for soil and water quality and Criterion 3. There are also implications of Indicator 2.4 for the sustainability of benefits from forests and for Indicators 5.3.1 and 5.3.2. These relationships are all reflected in the interaction matrix except for the latter two, which would not be considered a direct relationship.

- 1.3. Are there any overlaps or gaps in the relationship with indicators defined in Eddington and colleague’s (2009) report?

The FFEI indicator set has four indicators within the *Natural Disturbances* category, including Indicators 8 *Insects and Diseases*, 9 *Wind Throw*, 10 *Fire*, and 11 *Mass Movements*. However, there are no indicators that specifically address forest disturbance

arising from anthropogenic emissions, such as damage from ground-level ozone and acidifying soil compounds from acid rain.

2. Independent Climate-Change Assessment

- 2.1. Provide in detail, a qualitative description of what are the expected direct effects of climate change on the indicator, using a broad representation from the literature.

Tropospheric, or ground-level, ozone is a greenhouse gas that is a product of photochemical reactions with other compounds derived mainly from anthropogenic emission. The concentration of ground-level ozone has been greatly exacerbated due to the burning of fossil fuels and biomass, and is a direct radiative forcing agent of climatic change (Sitch et al., 2007). Concentrations of ground level-ozone are predicted to increase under future emissions scenarios, exceeding 70 ppb by 2100 in eastern and western North America under the SRES A2 Scenario (IPCC, 2007). Another possible threat of climate change is increasing ground-level ozone concentrations because of the interaction of temperature variability and warming with the photochemical processes that produce ozone (Pagnotti, 1990; McKendry, 1993).

Ground-level ozone damages plant cells and can lead to declines in forest productivity and biological diversity, as well as a reduced ability to uptake atmospheric CO₂ (Krzyzanowski et al., 2005; CCFM, 2006; Sitch et al., 2007). We can therefore expect increasing disturbance from ground-level ozone in Canada's forests over the coming decades. The reduction in carbon-uptake potential of forests has major implications for the role of forests in global carbon cycles and may also negate any potential benefits to NPP from carbon fertilization (Sitch et al., 2007).

Acid rain and the deposition of sulphur and nitrate is a result of major increases in the combustion of fossil fuels over the past century, and has major implications for water and soil quality and the integrity of forest ecosystems (Aber et al., 1989). Sulphur and nitrate deposition are very closely linked with precipitation regimes, and areas expected to experience an increase in precipitation under climate change have subsequently been predicted to have an increase in deposition (Langner et al., 2005). Conversely, areas predicted to have a decrease precipitation might have a similar decrease in wet deposition of sulphur and nitrate. However, this might be substituted by an increase in dry deposition, which is the direct deposition of atmospheric acidifying compounds in the absence of precipitation (Langner et al., 2005).

It is important to make a distinction about the nature of climate-change interaction with Indicator 2.4. The driving forces behind acid rain and ozone disturbance described above are a result of increasing anthropogenic emissions from burning fossil fuels, which is a driver of, not a response to, climate change that is driven by human activity. However, there is some potential for the interaction of tropospheric ozone and acid rain with climate change.

- 2.2. Given expected changes in Canada's climate, describe if and how the indicator's ability to signal progress towards SFM remains unchanged.

Adverse effects of ozone and acid rain on forest ecosystems will likely occur as a result of increasing anthropogenic emissions over the next century, and from the influence of climate warming on the damage arising from these pollutants (IPCC, 2007).

Given the predictions of future emissions scenarios, we can expect some increase in the area of forest disturbed by ozone and acid rain, and a corresponding increase in the relevance of Indicator 2.4 that is almost entirely external to climate change. There will be some decline in the predictability of the Indicator due the influence of changing precipitation rates and temperature with acid rain and tropospheric ozone, respectively. However, we feel that Indicator 2.4 will remain largely unchanged in its ability to signal SFM progress.

- 2.3. If an indicator's ability to signal progress towards SFM will be changed, describe if and how the indicator may become worse or better at signalling SFM progress.

There will be no change in the ability of Indicator 2.4 to signal SFM progress.

3. Integrated Climate-Change Assessment

- 3.1. What are the key determinants of the indicator (i.e. what causes it to change when it does change);

a) Among other indicators in the C&I framework?

- **Indicator 2.2 is a determinant of Indicator 2.4. For example, in recent afforestation initiatives in the Mixedwood Plains ecozone, plantations were established within the region with the highest levels of ground-level ozone and critical load exceedance of acidifying soil compounds (CCFM, 2006). Therefore, by default there are increases in the area of forest affected by ozone and acid rain.**
- **Forest sector carbon emissions (Indicator 4.1.4), though not a major contributor to national emissions rates, can be a source of acid rain and ground-level ozone and a determinant of Indicator 2.4.**

b) Among determinants not within the C&I framework?

- **Anthropogenic emissions resulting from the burning of fossil fuels, primarily from industrial activities and transportation, are by far the most important determinants of Indicator 2.4.**

- **In response to emissions causing ground-level ozone increases and acid rain and soil deposition, the Canadian government has taken steps towards climate-change mitigation with initiatives like the Canada-wide Standard for Ozone implemented in 2000 and the Acid Rain Strategy implemented in 1998 (CCFM, 2006). Government action like this is thereby a determinant of Indicator 2.4.**

3.2. For what other entities is this indicator a key determinant (i.e. when it changes, what other indicators are influenced to change);

a) Among other indicators in the C&I framework?

- **The effects of ozone and acidifying compounds are detrimental to plant physiology and soil ecology, making Indicator 2.4 a determinant of Indicators 2.1, 2.5, 4.1.1, and 4.1.2.**
- **Higher vulnerability to introduced and endemic pathogens and insects, such as the forest tent caterpillar, can result from the effects of ground-level ozone and acidifying soil compounds. Therefore, Indicator 2.4 can be seen as a determinant of Indicator 2.3.**
- **Indicator 2.4 tracks entities that are detrimental to forest biodiversity, and is a determinant for all indicators within Element 1.1 and the majority within Element 1.2.**

b) Among determinants not within the C&I framework?

- **The complex effects of tropospheric ozone and acid rain on soil microorganism diversity and nutrient levels are external to the C&I framework, as are many of effects of ozone on plant physiological processes, like stomatal conductance.**

3.3. To what degree can we now, on the basis of extant knowledge, establish how the key determinants interact cumulatively in influencing the indicator?

These two emissions-based pollutants interact cumulatively with each other and with timber harvests in forests and forest soils to cause nutrient depletion, soil microorganism and fauna mortality, and declines in plant productivity (Arp et al., 2001; CCFM, 2006). This cumulative interaction of ground-level ozone and acidifying soil compounds also makes it difficult to predict necessary emission reductions targets.

- 3.4. Is the indicator largely unrelated to any other, as described by the linkages assessment and evaluation of key determinants? If so, and the indicator was defined as uninfluenced by climate change in the independent assessment, then it can be placed in category one.

Indicator 2.4 is for the most part linked only to other indicators and external variables that are influenced by it. However, the key determinant of Indicator 2.4 is anthropogenic emissions, which are predicted to increase over the next century and will likely have an increasing impact on Canada's forests. As such, we do not recommend assignment to category one.

- 3.5. Do the indirect effects of climate change via the linkages with other indicators influence the indicator's ability to signal SFM, regardless of which category was assigned in the independent climate-change assessment?

There is no major indirect influence of climate change on the ability of Indicator 2.4 to signal SFM via linkages with other indicators. One exception could be Indicator 2.2 and afforestation initiatives to mitigate climate change in regions with high levels of ground-level ozone and acid rain.

- 3.6. If the indicator's ability to signal SFM progress remains the same under a changing climate, can we conclude no negative influence and leave it unchanged? These indicators can be placed in category two.

An increase in relevance under climate change rarely warrants indicator modifications. We also feel that the decline in predictability of Indicator 2.4 will be marginal, and we can safely assign it to category two, *Unmodified Indicators*.

- 3.7. If the indicator's ability to signal SFM progress deteriorates when one assumes a changing climate, then what modifications are possible or warranted to improve its ability sufficiently for it to remain among the C&I-SFM? These indicators can be placed in category three.

Not applicable. Indicator 2.4 will not need modification to maintain effectiveness in future assessments of C&I-SFM in Canada.

- 3.8. If no modifications seem possible or warranted, are we ready to recommend abandonment of the indicator? These indicators can be placed in category four.

Not applicable.

- 3.9. If we recommend abandonment, can we identify any new and closely allied indicators that might suit our needs better under climate change? Are there any other reasons for the creation of an additional indicator? These indicators can be placed in category five.

Not applicable.

- 3.10. Have extant climate-change impacts made this indicator more pertinent to SFM (i.e. 2.3 and the mountain pine beetle)? These indicators can be placed in category five or considered for conversion from a supporting to a core indicator (where applicable).

It is widely known that ground-level ozone and acid rain have been an increasing phenomenon in the past decades, and the impacts of these pollutants on forests is well researched (CCFM, 2006). For example, Krzyzanowski and colleagues (2006) conducted a study in the Lower Fraser Valley in British Columbia and found above-average and increasing concentrations of ground-level ozone. Preliminary research also found symptoms of ozone damage of native forest plants. However, there are no major research initiatives that we are aware of that have found significant interactions of climate change with acid rain and ground-level ozone.

- 3.11. How should the surviving indicator (the original, modified, or new) be modelled and monitored so that stronger SFM signals may be generated?

Ozone concentrations are monitored under the Canada-United States Air Quality Agreement, which provides the average annual fourth highest daily maximum eight-hour ozone concentration in its annual progress report (Canada-United States Air Quality Committee, 2010), and is used in the assessment of Indicator 2.4. The area of forest affected by acid rain is determined by critical load exceedances of acidifying compounds in forest soils. Data come from a variety of sources for this variable, mainly in the peer-reviewed literature and government research publications that rely on simulation modelling techniques to estimate critical load exceedances (Arp et al., 2001; Ouimet et al., 2001; Watmough et al., 2004; Langner et al., 2005). The refinement of critical-load models is an on-going process (CCFM, 2006). However, climate change will not necessitate any major changes to the measurement and monitoring of Indicator 2.4.

- 3.12. Does this indicator track an entity whose relationship with climate is regionally variable?

Ground-level ozone and acid rain are most concentrated in heavily populated regions of Canada, such as the Windsor-Quebec corridor, southern British Columbia, and southern Atlantic Canada. Despite this regional variability, there is no major divergence in the effectiveness of Indicator 2.4 in monitoring the area of forest affected by ozone and acid rain, save only the usual restrictiveness of data availability.

INDICATOR 2.5 PROPORTION OF TIMBER HARVEST AREA SUCCESSFULLY REGENERATED

1. Linkages Assessment

Table 1.1. Indicators influencing Indicator 2.5.

Indicator 2.5	Influencing Indicators
First order positive	1.3.1, 2.3, 3.1, 3.3, and 6.4.2
First order negative	1.2.2, 1.2.3, 1.2.4, and 2.4
First order bi-directional	5.2.1, 5.3.1, and 6.5.4

Table 1.2. Indicators influenced by Indicator 2.5.

Indicator 2.5	Influenced Indicators
First order positive	1.1.1, 1.2.2, 1.2.3, 2.1, 2.2, 2.3, 4.1.1, 4.1.2, 5.3.1, and 5.3.2
First order negative	None
First order bi-directional	6.5.4

- 1.1. Which indicators are influencing and influenced directly (first-order interactions) by the indicator in question? Is the indicator more of a driver of change in other indicators, or being driven by other indicators?

Indicator 2.5 influences 11 other indicators, from all Criteria except for Criterion 3, and is in turn influenced by 12 indicators, from all Criteria. This Indicator therefore appears to be both a driver of change and driven to change in relation with other indicators.

- 1.2. List the indicators described as ‘relevant indicators under other criteria’ in the 2003 C&I-SFM. Is there any conflict with the interactions described in the matrix?

Criterion 2, and subsequently Indicator 2.5, is described as an important driver for species diversity, as indicated by Indicators 1.2.1, 1.2.2, and 1.2.3. Other indicators are also described as relevant to the condition and productivity of an ecosystem, such as Indicator 1.1.1 because they indicate ecosystem diversity and are related to forest resilience. Abiotic ecosystem components such as soil quality are also critical to Criterion 2 and especially Indicator 2.5. These can in part be indicated by compliance with soil standards, as represented by Indicator 3.1. The results of the interaction matrix are mostly in line with the relevant indicators described in the 2003 C&I framework as they pertain to Indicator 2.5.

- 1.3. Are there any overlaps or gaps in the relationship with indicators defined in Eddington and colleague’s (2009) report?

There are five indicators under the *Biodiversity* category in the Eddington and colleagues (2009) report, with Indicator 13 *Ecosystem Productivity* being the most relevant to Indicator 2.5. The effects of climate change on the productivity of an ecosystem will be diverse and complex, both in British Columbia and across Canada, ranging from increasing growth rates and biomass accumulation due to higher temperatures and longer growing seasons, to declining overall productivity caused by more frequent and severe natural disturbances (Eddington et al., 2009; Williamson et al., 2009). Ecosystem productivity will also be affected by the climate-driven shift in tree species ranges (McKenney et al., 2007). In light of these predictions, ecosystem productivity will be a vital component of SFM to monitor and assess as the climate changes.

FFEI Indicator 14 is a fairly inclusive indicator of ecosystem productivity that may be more comparable to Criterion 2 in design, than to single indicators within. However, potential indicator variables and data sources for Indicator 14 suggest it is most closely related to Indicator 2.1, and to a lesser extent Indicators 2.2 and 2.5.

2. Independent Climate-Change Assessment

- 2.1. Provide in detail, a qualitative description of what are the expected direct effects of climate change on the indicator, using a broad representation from the literature.

Climate change and forest ecosystem condition and productivity are tightly linked, as forests are both heavily influenced by climate variation, as well as drivers of global climate cycles (Noss, 2001; Kurz et al., 2008; Johnston et al., 2010). By sequestering and storing atmospheric carbon in woody biomass, trees and forests have the potential to act as sinks of atmospheric carbon, thus mitigating the potential impacts of climatic change (Goodale et al., 2002). This relationship is addressed in more depth with the evaluation of Indicators 4.1.1 and 4.1.2.

There is a multitude of predicted and possible impacts of climate change on the regeneration of harvested stands across Canada, most of which are believed to be detrimental to the regeneration stage of forest growth and succession. Direct effects of climate change include shifts in the potential ranges of tree species, altered growth rates and productivity, and changes in seed production and seedling survival (van der Meer et al., 2002; Xu et al., 2009; McKenney et al., 2007; Johnston et al., 2009; Thomson et al., 2009). Some of these predicted impacts will pertain mainly to naturally regenerating areas, like changes in seed production, while others, like changes in the climatic ranges of tree species, will be important for natural regeneration and planted areas.

Trees are most vulnerable to climatic change in the regeneration stage, as the seedlings are far less tolerant to climatic extremes like drought and severe precipitation events (Johnston et al., 2009). Seedling establishment and growth will also be heavily influenced by latitudinal and altitudinal shifts in ranges (McKenney et al., 2007; McKenney et al., 2009). In addition to a simple change in what can grow where, these range shifts will likely be detrimental for regeneration because it is believed the climate is changing at a rate that is

faster than most tree species can migrate, and migration is usually further impeded by natural and anthropogenic barriers to dispersal (Scheller and Mladenoff, 2005). Furthermore, climate change will affect individual tree species in varying ways within established ecosystems, which may cause unexpected changes in community assemblages and ecological processes like competition and succession (Webb & Bartlein, 1992; Steenberg et al., 2010). The influence of climate change on seed production is another predicted impact, and will be highly variable between species and regions. In a modelling simulation of stand development in a changing climate, van der Meer and colleagues (2002) found that changes in seed production were highly influential on stand development and forest productivity.

- 2.2. Given expected changes in Canada's climate, describe if and how the indicator's ability to signal progress towards SFM remains unchanged.

Indicator 2.5 will likely be among the indicators most affected by climate change within the biophysical indicator set. We can confidently surmise that the Indicator will experience major declines in predictability and responsiveness because of the anticipated impacts of climate change. The relevance of Indicator 2.5 to SFM could be seen to increase given the vulnerability of forest regeneration to climate change. Conversely, we must also point out that any decline in responsiveness must be accompanied by a decline in relevance, because the reaction of an entity or phenomenon to management actions has been changed from its known condition or direction. Despite these declines in indicator strength, the regeneration of timber harvest area will still remain a vital piece of information pertaining to SFM that necessitates monitoring, as successful and timely regeneration of timber harvests are critical to maintaining ecosystem productivity and a sustainable flow of ecosystems goods and services (CCFM, 2006).

- 2.3. If an indicator's ability to signal progress towards SFM will be changed, describe if and how the indicator may become worse or better at signalling SFM progress.

Indicator 2.5 will decline in its ability to signal SFM progress.

3. Integrated Climate-Change Assessment

- 3.1. What are the key determinants of the indicator (i.e. what causes it to change when it does change);

- a) Among other indicators in the C&I framework?
- **Indicators within Element 1.2 are important determinants for Indicator 2.5, as stand regeneration is sensitive to both over-browsing from forest-associated species and competition and disturbance from native and invasive/alien species (Price et al., 2001).**

- The condition of forest ecosystems will be important determinants of regenerative success, which is linked to the level of disturbance from natural and anthropogenic sources, as represented by Indicators 2.3, 3.3, and 2.4.
- Forest policy and regulation in Canada's jurisdictions pertaining to regeneration on Crown land are also determinants of Indicator 2.5. Therefore, Indicators 3.1, 6.4.2, and 6.5.4 are also key determinants of Indicator 2.5.

b) Among determinants not within the C&I framework?

- There is a myriad of biological and phenological variables of trees that are key determinants of regeneration and stand development. Key examples include leaf phenology and seed production, with seed production being particularly important for regeneration (van der Meer et al., 2002).
- Forest regeneration is influenced by ecological and successional processes such as *intra*- and *inter*-specific competition, both with competing tree species and grasses and shrubs.
- Regeneration is also highly dependent on site factors, such as slope, aspect, exposure, and soil type, moisture, and nutrients. Soil condition is partially addressed by Indicator 3.1, but the close relationship of soil moisture and nutrient regimes and regeneration are external to the C&I framework.
- Aside from anthropogenic climate change, annual climate variation alone is a key determinant of regeneration. Seed production is closely linked with the climate of previous years and seedling establishment and growth are highly sensitive to climatic variation (Pickett & White, 1985). As such, climate is a key determinant in the distribution of tree species in Canada (McKenney et al., 2007).

3.2. For what other entities is this indicator a key determinant (i.e. when it changes, what other indicators are influenced to change);

a) Among other indicators in the C&I framework?

- The successful regeneration of timber harvests is definitely be a key determinant of growing stock and forest carbon storage, as well as forest cover and age-class distribution, as tracked by Indicators 1.1.1, 2.1, 4.1.1, and 4.1.2. Moreover, deletions of forest area, tracked by Indicator 2.2 can be caused by failed regeneration of timber harvests.
- Just as browsing, disturbance, and competition from forest-associated species and invasives can affect the regeneration of timber harvests, the same can be said for the

role of regenerating forest area as habitat and food sources for these species. Therefore, indicators within Element 1.2 are in part determined by Indicator 2.5.

b) Among determinants not within the C&I framework?

- **Regeneration of cutovers is a key determinant of future forest composition, especially in planted and silviculturally managed stands. This is addressed at a coarse resolution in Indicator 1.1.1, but never at the species level. Given the predicted magnitude of climate-driven changes in forest composition, this relationship may increase in validity, as will adaptive measures in stand regeneration.**
- **Prompt regeneration of timber harvests is highly important for soil and water quality, as timber harvests, especially clear-cuts, have been linked to soil degradation and erosion, and sedimentation and eutrophication in nearby surface waters (Swank et al., 2001). This issue is alluded to in the assessment of Indicator 3.3 (CCFM, 2006), but may warrant further development.**

3.3. To what degree can we now, on the basis of extant knowledge, establish how the key determinants interact cumulatively in influencing the indicator?

Indicator 2.5, as with the majority of the biophysical state indicators, can be susceptible to cumulative effects from the interaction of its determinants. For example, in a harvested stand of balsam fir in the Atlantic Maritime ecozone, climatic variations of previous years in combination with stress from the spruce budworm may to poor seed production in residual stands (van der Meer et al., 2002). Furthermore, less severe winters in the past several years would lead to an increase in the deer populations, which browse on the balsam fir regeneration (Thompson et al., 1998). Stand regeneration might be able to succeed one of these stressors, but combined they may inhibit proper and prompt stand regeneration.

3.4. Is the indicator largely unrelated to any other, as described by the linkages assessment and evaluation of key determinants? If so, and the indicator was defined as uninfluenced by climate change in the independent assessment, then it can be placed in category one.

Indicator 2.5 is highly related to other indicators in the C&I framework and to external determinants of change.

3.5. Do the indirect effects of climate change via the linkages with other indicators influence the indicator's ability to signal SFM, regardless of which category was assigned in the independent climate-change assessment?

Indirect influence of climate change via other indicators is likely to affect the regeneration of timber harvest areas. One concern is that the effects of climate change on tree species phenology and distribution will cause severe and unpredictable changes in forest-community dynamics and competitive regimes with other trees and other types of vegetation. Climate change is also predicted to favour some invasive forest pests and forest-associated species, which could lead to both high levels of disturbance from insect damage and over-browsing. Finally, changes in soil moisture and nutrient regimes due to climate change will likely affect regeneration patterns. Interestingly, one prediction is that the increasing rate of decomposition of woody debris in the elevated temperature will be beneficial for forest regeneration and growth by increasing nutrient levels in the soil (Saxe et al., 2001; Verburg, 2005).

- 3.6. If the indicator's ability to signal SFM progress remains the same under a changing climate, can we conclude no negative influence and leave it unchanged? These indicators can be placed in category two.

The ability of Indicator 2.5 to signal SFM progress will be diminished by the predicted changes in climate. The number of interacting determinants and sheer complexity and uncertainty surrounding the influence of climate change on Indicator 2.5 necessitate some form of action. We feel that the best approach here will be to create an additional indicator. However, successful regeneration of timber harvest area is vital to forest ecosystem functioning and to the forest sector, so we do not recommend abandoning the original Indicator 2.5. This Indicator can therefore remain unmodified and be placed in category two, *Unmodified Indicators*.

- 3.7. If the indicator's ability to signal SFM progress deteriorates when one assumes a changing climate, then what modifications are possible or warranted to improve its ability sufficiently for it to remain among the C&I-SFM? These indicators can be placed in category three.

Not applicable.

- 3.8. If no modifications seem possible or warranted, are we ready to recommend abandonment of the indicator? These indicators can be placed in category four.

Not applicable.

- 3.9. If we recommend abandonment, can we identify any new and closely allied indicators that might suit our needs better under climate change? Are there any other reasons for the creation of an additional indicator? These indicators can be placed in category five.

The regeneration phase is the point when forest managers have the greatest control over future forest conditions, and given its vulnerability to climate change and importance for forest ecosystems and sustainable wood supplies, further attention in the C&I framework may be warranted. While we do not recommend abandoning Indicator 2.5, the aforementioned issues may necessitate a new indicator related to the regeneration of timber harvest areas in a changing climate.

A new indicator that tracks climate-change adaptation initiatives pertaining to reforestation and regeneration may be the best approach to offsetting the deterioration of Indicator 2.5. Modifying seed transfer zones and new provenance tests to accommodate the latitudinal and altitudinal shifts in tree species ranges are some of the assisted migration suggestions for climate-change adaptation (Johnston et al., 2009; Johnston et al., 2010). We therefore propose the *Area of Crown Forest with Assisted Migration Initiatives* as a new indicator for the C&I framework.

- 3.10. Have extant climate-change impacts made this indicator more pertinent to SFM (i.e. 2.3 and the mountain pine beetle)? These indicators can be placed in category five or considered for conversion from a supporting to a core indicator (where applicable).

Extant climate-change impacts have been documented in Canada, and indeed make Indicator 2.5 and the entire aspect of forest regeneration more pertinent to SFM. Aspen species (*Populus* spp) provide a useful example of documented climate-change impacts. Evidence of aspen advancement into higher altitudes in the upper foothills region of Alberta (Landhäusser et al., 2010) and aspen dieback in the western Canadian interior (Hogg et al., 2008) have both been in-part attributed to the current changes in climate. As previously mentioned, the regeneration phase is the most vulnerable to climatic variability. These extant climate-change impacts further enforce the importance of monitoring natural and artificial regeneration within the managed forests of Canada.

- 3.11. How should the surviving indicator (the original, modified, or new) be modelled and monitored so that stronger SFM signals may be generated?

Continuity is a crucial component in any monitoring initiative. As such, the previous assessments of natural and artificial regeneration on Crown land (CCFM, 2000; CCFM, 2006) reinforce the continuation of this monitoring and assessment strategy for the surviving Indicator 2.5.

The foundations of climate-change prediction and forest-ecosystem vulnerability are future-oriented in nature. They rely heavily on experimentation and forecasting with a multitude of intricate and diverse simulation models that range from complex, global scale, general circulation models (GCMs) for climate change prediction to simpler, stand-level growth and yield models of productivity estimation. We suggest a new indicator to track assisted migration efforts across Canada in response to possible changes in tree-species distributions and provenances. Assisted migration initiatives that are tracked by this

indicator would rely heavily on forecasting with simulation modelling tools, such as those developed by McKenney and colleagues (2007) with the Canadian Forest Service that model possible changes in tree species ranges under different climate scenarios.

3.12. Does this indicator track an entity whose relationship with climate is regionally variable?

The regeneration of timber harvest area is highly vulnerable by regional variability in climate changes.

INDICATOR 3.1 RATE OF COMPLIANCE WITH LOCALLY APPLICABLE SOIL DISTURBANCE STANDARDS

1. Linkages Assessment

Table 1.1. Indicators influencing Indicator 3.1.

Indicator 3.1	Influencing Indicators
First order positive	6.4.2
First order negative	None
First order bi-directional	6.5.4

Table 1.2. Indicators influenced by Indicator 3.1.

Indicator 3.1	Influenced Indicators
First order positive	2.1, 2.5, 4.1.1, 4.1.2, and 6.4.2
First order negative	None
First order bi-directional	None

- 1.1. Which indicators are influencing and influenced directly (first-order interactions) by the indicator in question? Is the indicator more of a driver of change in other indicators, or being driven by other indicators?

Indicator 3.1 is only influenced by two indicators, Indicators 6.4.2 and 6.5.4, which both relate to forest management regulations, standards, and guidelines. It influences five other indicators, the majority of which are forest-ecosystem conditions that will be affected by soil disturbance. Indicator 3.1 is more of a driver of change than driven to change by other indicators.

- 1.2. List the indicators described as ‘relevant indicators under other criteria’ in the 2003 C&I-SFM. Is there any conflict with the interactions described in the matrix?

Ecosystem condition and productivity (Criterion 2) are closely linked with soil conservation and disturbance, and thus related to Indicator 3.1. Other indicators that are relevant to Indicator 3.1 are 6.5.4 and 6.5.3 as they both pertain to the development of new laws, standards, and guidelines. The relevant indicators described in the 2003 C&I-SFM are for the most part in line with the results of the interaction matrix, excluding Indicator 6.5.3 that would not be seen as a first-order interaction.

- 1.3. Are there any overlaps or gaps in the relationship with indicators defined in Eddington and colleague’s (2009) report?

The FFEI project is focused on monitoring key species and ecological processes in order to signal and anticipate the response of forest and rangeland to climate change. It does not

address policy, laws, standards, or guidelines of forest management, or compliance rates of forest practitioners.

2. Independent Climate-Change Assessment

- 2.1. Provide in detail, a qualitative description of what are the expected direct effects of climate change on the indicator, using a broad representation from the literature.

Soil disturbance, such as erosion, rut formation, compaction, and displacement, can often result from forest-management activities. As such, most jurisdictions have standards or requirements geared towards preventing major soil disturbances. Compliance with these standards varies, but was relatively high in the 2005 C&I-SFM assessment, ranging from 80% to 100% in the eight jurisdictions with available data (CCFM, 2006).

Climate change may have some negative implications for the maintenance of soil integrity in forest-management operations. Harvest operations are often scheduled for winter, as the frozen-ground conditions provide access to wetter or highly sensitive sites. This reduces many of the mentioned soil disturbances, especially soil compaction, which can result from harvest operations (Johnston et al., 2010). A shortening of this winter harvest season has already been experienced in Canada, and is predicted to worsen over the coming years (Spittlehouse & Stewart, 2003; Barrow et al., 2004; Johnston et al., 2010). These climate-change impacts indeed have implications for existing soil disturbance guidelines and standards and the formulation of new ones. However, there is no direct relation between climate change and the rate of compliance to these guidelines and standards.

- 2.2. Given expected changes in Canada's climate, describe if and how the indicator's ability to signal progress towards SFM remains unchanged.

Indicator 3.1 will not diminish in its ability to signal our progress towards SFM in a changing climate. As mentioned, there is potential for climate change to influence soil disturbance resulting from forest management activities, and consequently there may be an increase in the relevance of Indicator 3.1. Jurisdictional soil disturbance regulations and guidelines strive towards reflecting the most up-to-date science, including issues pertaining to climate change. However, the action of compliance with these standards and the action Indicator 3.1 are external to climatic conditions, and any current and future changes in climate.

- 2.3. If an indicator's ability to signal progress towards SFM will be changed, describe if and how the indicator may become worse or better at signalling SFM progress.

The ability of Indicator 3.1 to signal SFM progress will not decline under climate change.

3. Integrated Climate-Change Assessment

3.1. What are the key determinants of the indicator (i.e. what causes it to change when it does change);

a) Among other indicators in the C&I framework?

- **Indicator 6.4.2 is both a determinant and determined by Indicator 3.1.**
- **The update and creation of new ecological standards and guidelines in forest management, as tracked by Indicator 6.5.4, are determinants of Indicator 3.1.**

b) Among determinants not within the C&I framework?

- **The form and severity of contraventions that governing bodies or regulators administer for noncompliance is a determinant of Indicator 3.1.**
- **The training and qualifications of forest operators are a key determinant of practices that affect the level of soil disturbance, and subsequently of compliance rates.**
- **Third-party certification standards provided by the Forest Stewardship Council (FSC), Sustainably Forestry Initiative (SFI), and Canadian Standards Association (CSA) are influential on forest management practices and on compliance rates with soil standards and guidelines.**
- **Ethics, both of individuals and industry, are a determinant of Indicator 3.1.**

3.2. For what other entities is this indicator a key determinant (i.e. when it changes, what other indicators are influenced to change);

a) Among other indicators in the C&I framework?

- **Soil conditions play a front role in sustaining forest growth and productivity. The rate of compliance with soil disturbance standards, and by association the level of soil disturbance, are therefore determinants of Indicators from Criterion 2, especially Indicators 2.1 and 2.5.**

b) Among determinants not within the C&I framework?

- **Virtually all forest-associated flora and fauna rely on the soil either directly or indirectly in some stage of their life-cycle. The level of soil disturbance resulting**

from forest-management operations can have major implications for the health of forest ecosystems.

- **Soil disturbance from forest management activities is also a determinant of water quality and the hydrological functions of forests, as disturbances often lead to erosion and sedimentation of watercourses.**

3.3. To what degree can we now, on the basis of extant knowledge, establish how the key determinants interact cumulatively in influencing the indicator?

It is reasonable to assume that there is cumulative influence from the development of guidelines and standards that incorporate the most current science and research, training of forest practitioners, increasing frequency of third-party certification, and the frequency or intensity of audits and assessments of operations. However, because Indicator 3.1 is an action indicator, it is exceedingly difficult to estimate the degree to which these determinants and their interaction influence compliance rates with soil disturbance standards and guidelines.

3.4. Is the indicator largely unrelated to any other, as described by the linkages assessment and evaluation of key determinants? If so, and the indicator was defined as uninfluenced by climate change in the independent assessment, then it can be placed in category one.

Indicator 3.1 is designed to track the consequences of forest management for soil quality, which is a critical element of SFM. Existing and predicted climate-change impacts may also make Indicator 3.1 more relevant in future assessments. However, Indicator 3.1 is relatively unrelated to other indicators and was also found to be largely uninfluenced by climate change in the independent assessment. We can therefore assign it to category one, *Uninfluenced Indicators*.

3.5. Do the indirect effects of climate change via the linkages with other indicators influence the indicator's ability to signal SFM, regardless of which category was assigned in the independent climate-change assessment?

The rate of compliance with soil disturbance standards, and more importantly, the level of soil disturbance in cutovers are highly influential on several biophysical indicators that are highly influenced by climate change, such as Indicators 2.5 and 2.1. However, there are no indirect relationships that facilitate the influence of climate change on Indicator 3.1.

3.6. If the indicator's ability to signal SFM progress remains the same under a changing climate, can we conclude no negative influence and leave it unchanged? These indicators can be placed in category two.

Not applicable. The ability of Indicator 3.1 to signal progress towards SFM will not deteriorate, so it can remain unchanged and in category one.

- 3.7. If the indicator's ability to signal SFM progress deteriorates when one assumes a changing climate, then what modifications are possible or warranted to improve its ability sufficiently for it to remain among the C&I-SFM? These indicators can be placed in category three.

Not applicable.

- 3.8. If no modifications seem possible or warranted, are we ready to recommend abandonment of the indicator? These indicators can be placed in category four.

Not applicable.

- 3.9. If we recommend abandonment, can we identify any new and closely allied indicators that might suit our needs better under climate change? Are there any other reasons for the creation of an additional indicator? These indicators can be placed in category five.

Not applicable.

- 3.10. Have extant climate-change impacts made this indicator more pertinent to SFM (i.e. 2.3 and the mountain pine beetle)? These indicators can be placed in category five or considered for conversion from a supporting to a core indicator (where applicable).

The rising temperature has already had implications for forest-management operations. Warmer winter temperatures mean decreases in frozen-ground conditions and therefore shorter winter-harvest seasons (Johnston et al., 2010). For example, the winter of 2005-2006 did not yield frozen-ground conditions in Saskatchewan until January, much later than usual (Johnston et al., 2010). Operations in the winter-harvest seasons cause significantly less soil rutting and compaction, so these climate-change impacts have implications for Indicator 3.1, though they do not affect the rate of compliance directly.

- 3.11. How should the surviving indicator (the original, modified, or new) be modelled and monitored so that stronger SFM signals may be generated?

Data for this indicator come from provincial and territorial forest management agencies. Compliance assessments are carried out on both public and private forestland, either randomly or by public request, but often are concentrated in designated areas with high ecological risk from forest management activities (CCFM, 2006).

Given the growing popularity of third-party certification for forest management, there may be future opportunities for assessment data sources from the forest management audits that are part of these certifications.

3.12. Does this indicator track an entity whose relationship with climate is regionally variable?

There are no regional variations in the relationship between climate and rate of compliance with soil disturbance standards in the jurisdictions of Canada.

INDICATOR 3.2 RATE OF COMPLIANCE WITH LOCALLY APPLICABLE ROAD CONSTRUCTION, STREAM CROSSING AND RIPARIAN ZONE MANAGEMENT STANDARDS

1. Linkages Assessment

Table 1.1. Indicators influencing Indicator 3.2.

Indicator 3.2	Influencing Indicators
First order positive	6.4.2
First order negative	None
First order bi-directional	6.5.4

Table 1.2. Indicators influenced by Indicator 3.2.

Indicator 3.2	Influenced Indicators
First order positive	1.2.2, 1.2.3, 2.2, and 6.4.2
First order negative	1.2.1
First order bi-directional	None

- 1.1. Which indicators are influencing and influenced directly (first-order interactions) by the indicator in question? Is the indicator more of a driver of change in other indicators, or being driven by other indicators?

Indicator 3.2 is only influenced by two indicators, Indicators 6.4.2 and 6.5.4, which both relate to forest management regulations, standards, and guidelines. It influences five other indicators, the majority of which are from Element 1.2. Indicator 3.2 is more of a driver of change than driven to change by other indicators.

- 1.2. List the indicators described as ‘relevant indicators under other criteria’ in the 2003 C&I-SFM. Is there any conflict with the interactions described in the matrix?

Indicators that are described as relevant to Indicator 3.2 include Indicators 6.5.4 and 6.5.3, as they both pertain to the development of new laws, standards, and guidelines. Indicator 6.5.3 was not found to have a direct relationship with Indicator 3.2 in the interaction matrix.

- 1.3. Are there any overlaps or gaps in the relationship with indicators defined in Eddington and colleague’s (2009) report?

The FFEI project is focused on monitoring key species and ecological processes in order to signal and anticipate the response of forest and rangeland to climate change. It does not address policy, laws, standards, or guidelines of forest management, or compliance rates of forest practitioners.

2. Independent Climate-Change Assessment

- 2.1. Provide in detail, a qualitative description of what are the expected direct effects of climate change on the indicator, using a broad representation from the literature.

Climate change is predicted affect water quality and quantity in both managed and unmanaged forests (Mote et al., 2003; Spittlehouse, 2005). Extant impacts of climatic change on forested watersheds include reduced snowpack, earlier peak snowmelts, warmer summer water temperatures, and flooding (Hodgkins et al., 2003; Dettinger et al., 2004; Payne et al., 2004; Jones et al., 2009).

Many different forest-management activities, road construction and clear-cutting especially, can also have adverse effects on the hydrology of watersheds due to eutrophication, acidification, and sedimentation, and can adversely affect aquatic invertebrate communities (Trombulak & Frissel, 2000; Swank et al., 2001; Vaidya et al., 2008). Forest management guidelines and standards for road construction, stream crossings, and riparian buffer zones are preventative tools for the maintenance of water quality and quantity, and strive to minimize these impacts of forest management on water (CCFM, 2006). While there will certainly be interaction between these predicted climate-change impacts and the forest management guidelines and standards pertaining to maintaining natural hydrological processes, there is no direct linkage of climate change to the rate of compliance to these guidelines and standards.

- 2.2. Given expected changes in Canada's climate, describe if and how the indicator's ability to signal progress towards SFM remains unchanged.

There will be no decline in the ability of Indicator 3.2 to track SFM progress in a changing climate. However, as with Indicator 3.1, there will be some increase in its relevance to SFM. There are both observed and forecasted examples of climate-change influence on hydrological cycles (Jones et al., 2009) that will need to be addressed in updated road construction, stream crossing, and riparian zone management standards. However, climate change has no direct influence on the rate of compliance with current or future standards.

- 2.3. If an indicator's ability to signal progress towards SFM will be changed, describe if and how the indicator may become worse or better at signalling SFM progress.

Indicator 3.2 will remain unchanged in its ability to signal our progress towards SFM under climate change.

3. Integrated Climate-Change Assessment

3.1. What are the key determinants of the indicator (i.e. what causes it to change when it does change);

a) Among other indicators in the C&I framework?

- **Indicator 6.5.4 is both a determinant and determined by Indicator 3.2.**
- **The update and creation of new ecological standards and guidelines in forest management, as tracked by Indicator 6.5.4, are determinants of Indicator 3.2.**

b) Among determinants not within the C&I framework?

- **The severity of contraventions administered by governing bodies for noncompliance is a determinant of Indicator 3.2.**
- **Qualifications and the degree of training of forest operators are a key determinant of compliance rates in the field.**
- **The increasing incidence of third-party certification standards like those provided by the Forest Stewardship Council (FSC), Sustainably Forestry Initiative (SFI), and Canadian Standards Association (CSA) are determinants of forest-management practices, and subsequently of compliance rates with locally applicable standards and guidelines.**
- **There are also many less tangible, ethically-based determinants of Indicator 3.2.**

3.2. For what other entities is this indicator a key determinant (i.e. when it changes, what other indicators are influenced to change);

a) Among other indicators in the C&I framework?

- **Indicator 3.2 is relevant to forest habitat and as such is a determinant for Indicators in Element 1.2.**
- **The construction of permanent forest roads are a considerable source of permanent deforestation (CCFM, 2006), making Indicator 3.2 a partial determinant of Indicator 2.2.**

b) Among determinants not within the C&I framework?

- **Water quality, the maintenance of natural hydrological processes, and the health of a watershed are vital forest-ecosystem components for society that are in-part determined by Indicator 3.2, especially in heavily managed areas.**

- 3.3. To what degree can we now, on the basis of extant knowledge, establish how the key determinants interact cumulatively in influencing the indicator?

The cumulative effects of climate-induced forest change, forest management, and hydrology are highly uncertain. However, we must assume that factors such as jurisdictional variation in standards and guidelines, the qualifications and training of operators, and the total extent of third-party certification, amongst other things, will cumulatively influence local rates of compliance. It is difficult to discern the level of this influence because Indicator 3.2 is an action indicator.

- 3.4. Is the indicator largely unrelated to any other, as described by the linkages assessment and evaluation of key determinants? If so, and the indicator was defined as uninfluenced by climate change in the independent assessment, then it can be placed in category one.

Indicator 3.2 has some influential interactions with several indicators within the C&I framework and external determinants of change, but for the most part is unrelated to any other indicators influencing it. Moreover, Indicator 3.1 was found to be largely uninfluenced by climate change in the independent assessment. We can therefore assign it to category one, *Uninfluenced Indicators*.

- 3.5. Do the indirect effects of climate change via the linkages with other indicators influence the indicator's ability to signal SFM, regardless of which category was assigned in the independent climate-change assessment?

Direct climate-change influence on hydrological processes and indirect interactions due to changes in forest growth and productivity are pertinent to road construction, stream crossing, and riparian zone management standards, but do not affect the rate of compliance with these standards.

- 3.6. If the indicator's ability to signal SFM progress remains the same under a changing climate, can we conclude no negative influence and leave it unchanged? These indicators can be placed in category two.

Not applicable.

- 3.7. If the indicator's ability to signal SFM progress deteriorates when one assumes a changing climate, then what modifications are possible or warranted to improve its ability sufficiently for it to remain among the C&I-SFM? These indicators can be placed in category three.

Not applicable.

- 3.8. If no modifications seem possible or warranted, are we ready to recommend abandonment of the indicator? These indicators can be placed in category four.

Not applicable.

- 3.9. If we recommend abandonment, can we identify any new and closely allied indicators that might suit our needs better under climate change? Are there any other reasons for the creation of an additional indicator? These indicators can be placed in category five.

Not applicable.

- 3.10. Have extant climate-change impacts made this indicator more pertinent to SFM (i.e. 2.3 and the mountain pine beetle)? These indicators can be placed in category five or considered for conversion from a supporting to a core indicator (where applicable).

Climate-change impacts on surface-water hydrology have already been detected in Canada, such as the observed changes in water temperature and flow in the Fraser River system (Morrison et al., 2002). These experienced changes in hydrology are pertinent to Indicator 3.2, but perhaps have more implications for Indicators 6.5.4 and 3.3.

- 3.11. How should the surviving indicator (the original, modified, or new) be modelled and monitored so that stronger SFM signals may be generated?

Data for this indicator come from provincial and territorial forest-management agencies. Compliance assessments are carried out on both public and private forestland, either randomly or by public request, but often are concentrated in designated areas with high ecological risk from forest management activities (CCFM, 2006).

The development of the national standard for monitoring road construction, stream crossings, and riparian zone management that was alluded to in the 2005 C&I-SFM status report (CCFM, 2006) would be a useful tool for mitigating the disparities in reporting between jurisdictions.

- 3.12. Does this indicator track an entity whose relationship with climate is regionally variable?

There are no regional variations in the relationship between climate and rate of compliance with road construction, stream crossing, and riparian zone management standards in the jurisdictions of Canada.

INDICATOR 3.3 PROPORTION OF WATERSHEDS WITH SUBSTANTIAL STAND-REPLACING DISTURBANCE IN THE LAST 20 YEARS

1. Linkages Assessment

Table 1.1. Indicators influencing Indicator 3.3.

Indicator 3.3	Influencing Indicators
First order positive	1.2.4, 2.2, and 2.3
First order negative	1.1.2 and 2.1
First order bi-directional	1.1.1

Table 1.2. Indicators influenced by Indicator 3.3.

Indicator 3.3	Influenced Indicators
First order positive	1.2.1 and 2.5
First order negative	1.2.2, 1.2.3, 2.1, 4.1.1, and 5.3.1
First order bi-directional	1.1.2, 1.1.2, 4.1.2, and 5.3.2

- 1.1. Which indicators are influencing and influenced directly (first-order interactions) by the indicator in question? Is the indicator more of a driver of change in other indicators, or being driven by other indicators?

Indicator 3.3 influences 11 other indicators, many of which are from Criterion 1. It is influenced by six indicators, split evenly between Criteria 1 and 2. Naturally, Indicator 3.3 is very closely related to Indicator 2.3. Indicator 3.3 is more of a driver of change in other indicators than it is driven by them.

- 1.2. List the indicators described as ‘relevant indicators under other criteria’ in the 2003 C&I-SFM. Is there any conflict with the interactions described in the matrix?

Indicators described as relevant to soil and water in the 2003 C&I-SFM report are segregated into the policy and biophysical dimensions, the former of which includes Indicators 6.5.4 and 6.5.3. Several biophysical indicators are described as relevant, but not all have implications for Indicator 3.3, and those that do pertain only to the goal statement of the indicator, water quality, not the specific phenomenon of stand-replacing disturbances in watersheds. These include Indicators 2.2, 2.4, and 2.5.

These results correspond with the interaction matrix but for one exception. Indicator 2.4 tracks an entity that is highly related to water quality, yet has no direct relationship with Indicator 3.3, or any other indicators in Criterion 3.

- 1.3. Are there any overlaps or gaps in the relationship with indicators defined in Eddington and colleagues’ (2009) report?

All of the seven Indicators within the *Ecosystem Drivers* category of the FFEI indicator set are indicators of hydrological processes and variables. None of these indicators, excepting Indicator 7 *Unseasonable or Unexpected Weather Conditions*, are related to Indicator 3.3 specifically, but all share a goal of monitoring water quantity and quality within forest ecosystems.

2. Independent Climate-Change Assessment

- 2.1. Provide in detail, a qualitative description of what are the expected direct effects of climate change on the indicator, using a broad representation from the literature.

Indicator 3.3 has and will be directly influenced by climate change. The direct effects of climate are virtually identical in concept to those of Indicator 2.3. Natural disturbance regimes are expected to be altered due to climate change, and more frequent and severe events are predicted (Dale et al., 2001; Williamson et al., 2009).

While many areas are predicted to have an increase in precipitation, others may experience declines, especially during the growing season, leading to droughts that can severely impact forest ecosystems (Hogg et al., 2008). The 2001-2003 drought in the western Canadian interior caused significant aspen dieback and is believed to be partially attributed to climate change (Hogg & Bernier, 2005). The frequency and severity of extreme weather events is also expected to increase, leading to more catastrophic blowdowns and precipitation events (Peterson, 2000). The warmer climate may be advantageous for forest diseases and insect populations, causing longer and more frequent outbreaks, as already observed in British Columbia and Alberta with the mountain pine beetle (*Dendroctonus ponderosae*; Gray, 2008; Kurz et al., 2008). The relationship between forest fires and climate is highly complex, but it is predicted that the fire frequency and severity will increase in most Canadian ecozones and the instance of fires overwhelming fire management will be more recurrent (Flannigan et al., 2005; Williamson et al., 2009).

The proportion of watersheds that have sustained stand-replacing disturbances can certainly be expected to increase under these conditions. What are highly uncertain are the implications of climate change for water quality, and the dynamics of watershed hydrology, natural disturbances, and forest management (Jones et al., 2009).

- 2.2. Given expected changes in Canada's climate, describe if and how the indicator's ability to signal progress towards SFM remains unchanged.

The ability of Indicator 3.3 to signal our progress towards SFM will deteriorate under climate change.

- 2.3. If an indicator's ability to signal progress towards SFM will be changed, describe if and how the indicator may become worse or better at signalling SFM progress.

The ability of Indicator 3.3 to signal SFM will most likely deteriorate with climate change, due to declines in its predictability, responsiveness, and relevance. We also feel that there is some misalignment of Indicator 3.3 with its described goal of monitoring major changes in water yield, timing, and peak flow (CCFM, 2003), and thus some extant deficiencies in its relevance. Given this, the effects of climate change, and the described challenges to the feasibility of monitoring Indicator 3.3 (CCFM, 2006), we feel that some appropriate actions will be necessary for our ability to address the values outlined under Criterion 3.

3. Integrated Climate-Change Assessment

3.1. What are the key determinants of the indicator (i.e. what causes it to change when it does change);

a) Among other indicators in the C&I framework?

- Indicator 3.3 is directly influenced by six other indicators from Criteria 1 and 2. of these, indicators that are directly associated with forest disturbances are the key determinants, such as Indicators 2.3 and 1.2.4.**
- Given the importance of natural disturbance regimes for Indicator 3.3, the condition of the forest, tracked by Indicators 1.1.1 and 2.1, will also be a determinant because of its association with disturbance vulnerability.**
- Timber harvest is one of the possible stand-replacing disturbances that can occur within forested watersheds. As such, forest management activities, tracked by Indicator 5.3.1, are notable determinants for Indicator 3.3.**

b) Among determinants not within the C&I framework?

- The most influential determinant not within the C&I framework is climate. Natural disturbance regimes are highly dependent on climate (Frelich, 2002). Examples include blowdowns due to hurricanes and downbursts, insect and disease outbreaks associated with warmer winter temperatures, and fire and drought events attributed to changes in both temperature and precipitation. This emphasises the high probability that the extreme variation and long-term change in these variables associated with climate change will have a strong influence on Indicator 3.3.**
- There are also many determinants within the regulatory environment, such as acceptable practices in designated waters supply areas, which will be determinants of forest practices and subsequently stand-replacing disturbance by timber harvest.**
- The interrelatedness of disturbance events is also a critical determinant, as one form of disturbance usually makes a stand more susceptible to another, such as fuel**

accumulation from blowdowns and insect mortality leading to a greater risk of fire (Neily et al., 2007). While this concept is related to Indicator 3.3, it is not explicitly addressed.

3.2. For what other entities is this indicator a key determinant (i.e. when it changes, what other indicators are influenced to change);

a) Among other indicators in the C&I framework?

- **Indicator 3.3 has direct influence over 11 other indicators within the C&I framework, many of which are within Criterion 1. The level of disturbance within a forested watershed is a key determinant of ecosystem diversity (Element 1.1) and species diversity (Element 1.2).**
- **Other components of forest ecosystems that will be influenced by the level of disturbance include forest carbon, track by Indicators 4.1.1 and 4.1.2, and forest growth and productivity, tracked by Indicators 2.1 and 2.5.**

b) Among determinants not within the C&I framework?

- **Indicator 3.3 is a key determinant for water quality and quantity, and other hydrological variables such as streamflow, groundflow, and snowpack, which are not included in the C&I framework. Water is of course a key value outlined Criterion 3, but there is no direct inclusion of the aforementioned entities in the framework.**

3.3. To what degree can we now, on the basis of extant knowledge, establish how the key determinants interact cumulatively in influencing the indicator?

The cumulative nature of disturbance events and their effects on forest ecosystems are relatively well researched and documented. The vulnerability of forest ecosystems to one form of natural disturbance is often highly dependent on others, whereby the occurrence of one form of disturbance will lead to a higher propensity for another (Frelich, 2002). Wind-damaged stands are more susceptible to outbreaks of both native and exotic forest pests, especially since blowdown areas are focal points for the establishment of bark beetle populations (Magasi, 1995; Fleming & Candau, 1998). Insect mortality and blowdowns are also both sources of fuel accumulation, which are a major determinant of fire activity (Flannigan et al., 2001). Furthermore, salvage harvests resulting from disturbance events can also be seen to contribute to the cumulative influence of determinants on Indicator 3.3.

- 3.4. Is the indicator largely unrelated to any other, as described by the linkages assessment and evaluation of key determinants? If so, and the indicator was defined as uninfluenced by climate change in the independent assessment, then it can be placed in category one.

Indicator 3.3 is highly related to other indicators in the C&I framework and to external determinants of change.

- 3.5. Do the indirect effects of climate change via the linkages with other indicators influence the indicator's ability to signal SFM, regardless of which category was assigned in the independent climate-change assessment?

The effects of climate change on Indicator 3.3 are mainly direct effects, in the form of climate-driven changes in natural disturbance regimes. The most likely indirect influence of climate change will be changes in vulnerability to natural disturbances via climate-induced changes in forest type and structure, tracked by Indicators 1.1.1 and 1.1.2.

- 3.6. If the indicator's ability to signal SFM progress remains the same under a changing climate, can we conclude no negative influence and leave it unchanged? These indicators can be placed in category two.

Indicator 3.3 represents a difficult case, where the foundational goal of the indicator as a signal of the relationship of water to SFM is a vital component of Criterion 3. Indeed, the level of disturbance and thus the age of the forest have been proven to be key determinants of water quality and quantity. However, the feasibility of monitoring this relationship is exceeding fraught, regardless of climate change. Nevertheless, we recommend assigning the diminished Indicator to category two, *Unmodified Indicators*, though these limitations and the further deterioration of the Indicator under climate change necessitate some level of action, such as the creation of an additional indicator.

- 3.7. If the indicator's ability to signal SFM progress deteriorates when one assumes a changing climate, then what modifications are possible or warranted to improve its ability sufficiently for it to remain among the C&I-SFM? These indicators can be placed in category three.

Not applicable.

- 3.8. If no modifications seem possible or warranted, are we ready to recommend abandonment of the indicator? These indicators can be placed in category four.

Not applicable.

- 3.9. If we recommend abandonment, can we identify any new and closely allied indicators that might suit our needs better under climate change? These indicators can be placed in category five.

There are several possible options for new indicators to monitor the influence of forest sector activities on water. The monitoring initiative proposed in the Eddington and colleagues (2009) may provide some inspiration for additional indicators. The FFEI indicators track hydrological forest-ecosystem drivers that are predicted to change with the climate. They include precipitation, snowpack, streamflow, water temperature, water quality, glaciers, and unseasonable or unexpected weather events. While assessing all of these variables at the national scale may not be feasible or desirable, a single indicator that tracks changes and variation in hydrological cycles would be valuable to SFM monitoring under climate change. We propose *Quantity and Form of Precipitation* as a new indicator, as it a key determinant of the variables tracked by the FFEI indicators and has some level of data availability (CCME, 2003; Eddington et al., 2009).

- 3.10. Have extant climate-change impacts made this indicator more pertinent to SFM (i.e. 2.3 and the mountain pine beetle)? These indicators can be placed in category five or considered for conversion from a supporting to a core indicator (where applicable).

A well known example of extant climate-change impacts is the current outbreak of mountain pine beetle. The pine beetle is an endemic species, and has historically had periodic outbreaks when the conditions were favourable. The current outbreak in British Columbia and Alberta has surpassed all previous recorded outbreaks in duration and extent. The outbreak has been attributed both to climate change, namely warmer winter temperatures, and forest vulnerability from the history of management activities in the region (Kurz et al., 2008). The pine beetle has become a definitive example of the relationship between climate change, forest ecosystems, and forest management. Another example of a bark beetle outbreak attributed to climate change is the current outbreak of the spruce beetle (*Dendroctonus rufipennis*) in the Yukon, which again is the largest on record in the region (Berg et al., 2006). Similar examples of severe droughts (Hogg et al., 2008) and increased fire activity (Williamson et al., 2009) have also been attributed to recent changes in climate.

- 3.11. How should the surviving indicator (the original, modified, or new) be modelled and monitored so that stronger SFM signals may be generated?

The area forest affected by natural disturbances and timber harvest is available from the Canadian Council of Forest Ministers' National Forest Database (CCFM, 2010), and was the main data source in the 2005 assessment of Indicator 2.3. This clearly will be of continuing value in the monitoring of Indicator 3.3.

Monitoring the timing and rates of precipitation is a relatively expensive and demanding endeavour. However, there are already monitoring systems in place that future

assessments of the proposed indicator could draw from. The Canadian Centre for Climate Modelling and Analysis (CCCMA) also provides multiple modelling tools, such as the Canadian Regional Climate Model, which simulate historical climate estimations that are driven by the CCMA's Coupled Global Climate Model (CCCMA, 2009).

3.12. Does this indicator track an entity whose relationship with climate is regionally variable?

The influence of climate change on natural disturbance regimes will be highly variable between Canada's forested ecozones.

INDICATOR 4.1.1 NET CHANGE IN FOREST ECOSYSTEM CARBON

1. Linkages Assessment

Table 1.1. Indicators influencing Indicator 4.1.1.

Indicator 4.1.1	Influencing Indicators
First order positive	2.1, 2.2, 2.5, and 3.1
First order negative	1.2.2, 1.2.3, 1.2.4, 2.3, 2.4, 3.3, and 5.3.1
First order bi-directional	1.1.1, 1.1.2, 4.1.2, and 5.3.2

Table 1.2. Indicators influenced by Indicator 4.1.1.

Indicator 4.1.1	Influenced Indicators
First order positive	None
First order negative	None
First order bi-directional	1.2.1, 1.2.2, 1.2.3

- 1.1. Which indicators are influencing and influenced directly (first-order interactions) by the indicator in question? Is the indicator more of a driver of change in other indicators, or being driven by other indicators?

Indicator 4.1.1 only influences three other indicators, all of which are within Element 1.2. It is influenced by 15 indicators, from all Criteria except Criterion 6. As a condition/response indicator, Indicator 4.1.1 is heavily influenced by many different indicators and is not a very strong driver of change.

- 1.2. List the indicators described as ‘relevant indicators under other criteria’ in the 2003 C&I-SFM. Is there any conflict with the interactions described in the matrix?

Forest ecosystem carbon and a forest’s carbon budget is strongly related to the type, age, and area of forest, so any indicator that tracks one of these entities or something that strongly influences them will be relevant to Indicator 4.1.1. These include Indicators 1.1.1, 2.2, 2.3, and 3.3. This is all in agreement with the indicators directly influencing Indicator 4.1.1 in the interaction matrix.

- 1.3. Are there any overlaps or gaps in the relationship with indicators defined in Eddington and colleague’s (2009) report?

Indicator 13 *Ecosystem Productivity* in the *Biodiversity* category is the most closely related to Indicator 4.1.1 of the FFEI Indicators. The effects of climate change on the productivity of an ecosystem will be diverse and complex, both in British Columbia and across Canada, ranging from increasing growth rates and biomass accumulation due to higher temperatures and longer growing seasons to declining overall productivity caused by more frequent and severe natural disturbances (Eddington et al., 2009; Williamson et al., 2009).

Carbon sequestration, which can be inferred from ecosystem productivity, and ‘sink versus source’ data are also described as highly relevant in light of climate change in the Eddington et al. (2009) report.

FFEI Indicator 13 is a fairly inclusive indicator of ecosystem productivity that may be most comparable in design to Criterion 2 as a whole. The mention of the importance of carbon for ecosystem productivity is of course relevant to Indicators 4.1.1 and 4.1.2, but is in contrast to the goal of these indicators in the CCFM C&I-SFM in tracking the role of SFM in global ecological cycles, not in mitigating climate change. Conversely, we stress the importance of forests as carbon sinks for Indicator 4.1.1 in this evaluation.

2. Independent Climate-Change Assessment

- 2.1. Provide in detail, a qualitative description of what are the expected direct effects of climate change on the indicator, using a broad representation from the literature.

Climate change is predicted to influence the productivity of terrestrial biomes, including forests, significantly (Schimel et al., 2001). However, these effects will most likely be extremely variable by region, with increases in productivity in high altitudes and latitudes (Chaplin et al., 1995) and decreases in productivity in nutrient- and moisture-limited or drought prone areas (Friend, 2010).

The most frequent prediction is that climate change will be favourable for the metabolic processes of trees, photosynthesis and respiration in particular, leading to an increase in forest productivity (Norby et al., 2005). Furthermore, the predicted increases in temperature may lead to longer growing seasons when trees are metabolically active, and therefore more time to sequester carbon and accumulate biomass (McMahon et al., 2010). Climate change may also influence the dead organic matter carbon pool through altered decay rates caused by changes in soil moisture and temperature (Stinson et al., 2011).

An additional influence of climate change on forest productivity is that of carbon fertilization. This refers to a complex process where trees can maintain higher rates of photosynthesis in higher atmospheric CO₂ concentrations because of lowered stomatal conductance and greater water-use efficiency (Friend, 2010). This in turn leads to increases in forest productivity. However, there is debate as to the overall influence of carbon fertilization (Gitay et al., 2001). Indeed, as with most climate-change predictions, the effects of climate change on forest productivity, and subsequently forest carbon, are uncertain and variable (Williamson et al., 2009). It is often stated that climate-driven changes in natural disturbance regimes will be the ultimate determinant of forest-ecosystem productivity in the coming decades (Dale et al., 2001).

The anticipated increase in natural-disturbance frequency and magnitude have ramifications for forest-ecosystem carbon budgets, and may be the final determinant of whether a forest is a source or sink of atmospheric carbon (Kurz et al., 2008; Slaney et al., 2009). Kurz and colleagues (2008) illustrated the major loss of carbon uptake potential and

future emissions from decaying trees caused by the mountain pine beetle (*Dendroctonus ponderosae*) epidemic in western Canada. Fire is also a major emitter of forest carbon when large quantities of stored carbon are burned and released to the atmosphere, and is also anticipated to increase in frequency and severity (Flannigan et al., 2009).

- 2.2. Given expected changes in Canada's climate, describe if and how the indicator's ability to signal progress towards SFM remains unchanged.

The ability of Indicator 4.1.1 to signal SFM progress will not remain the same under climate change.

- 2.3. If an indicator's ability to signal progress towards SFM will be changed, describe if and how the indicator may become worse or better at signalling SFM progress.

Indicator 4.1.1 will more than likely deteriorate under climate change. This is partially because of a major decline in predictability, due largely to the changing frequency and magnitude of natural disturbances. However, the change in the ability of Indicator 4.1.1 to track SFM progress is also due to a decline in its measurability. Climate change is predicted to affect the physiological growth rate of trees and the productivity of forests, as well as decomposition rates of dead organic matter, which will invalidate some of the core assumptions of how we measure net changes in forest carbon (Linder, 2000; Verburg, 2005). Because these assumptions are intrinsic to the forest carbon budget models that are used to measure Indicator 4.1.1, we can anticipate a decline in the measurability and overall ability of the Indicator. Conversely, there is also a major increase in the relevance of Indicator 4.1.1, as there is for all indicators within Criterion 4, because of the growing recognition of forests to mitigate climate change by acting as sinks of atmospheric carbon under international agreements like the UNFCCC and Kyoto Protocol (Freedman et al., 2009).

3. Integrated Climate-Change Assessment

- 3.1. What are the key determinants of the indicator (i.e. what causes it to change when it does change);

- a) Among other indicators in the C&I framework?
 - **Key determinants among the indicators influencing Indicator 4.1.1 include Indicators 1.1.1, 2.1, and 4.1.2.**
 - **Natural disturbance regimes and timber harvests are also highly influential on forest carbon, making Indicators 2.3, 3.3, and 5.3.1 determinants of Indicator 4.1.1.**

- **Forest policy, laws, and management guidelines and standards are also important determinant, such as those tracked by Indicator 6.5.4.**

b) Among determinants not within the C&I framework?

- **The growth and productivity of trees and subsequent storage of carbon in woody biomass is a complex set of processes that are influenced by a wide array of factors. Geomorphology, climate, and soil are determinants of the carbon stored in plants (Pastor & Post, 1986), and the carbon cycle in forests also depends on decomposition, combustion during fires, and removal of carbon during timber harvest.**
- **There are also agents of change in the forest landscape that will determine the net change in forest carbon at a much broader scale. Other than the previously described role of natural disturbances, human activities are most likely the key determinant of the net change in carbon in much of Canada. These activities include development and urbanization, agriculture, oil and gas activities, and of course forest management. While many of these are tracked by Indicator 2.2, many are also external to the C&I framework.**

3.2. For what other entities is this indicator a key determinant (i.e. when it changes, what other indicators are influenced to change);

a) Among other indicators in the C&I framework?

- **The only indicators that are in part determined by Indicator 4.1.1 are within Element 1.2, because of the affiliation of forest carbon with habitat conditions. These include Indicators 1.2.1, 1.2.2, and 1.2.3.**

b) Among determinants not within the C&I framework?

- **The net change in forest carbon is a biophysical state indicator, and as such it is not a strong driver for other processes. However, as its placement in Criterion 4 and Element 4.1 implies, Indicator 4.1.1 is a determinant for different components of the carbon cycle. Forests, as part of the biosphere, influence the carbon that is also cycled through the atmosphere, soil, and water.**

3.3. To what degree can we now, on the basis of extant knowledge, establish how the key determinants interact cumulatively in influencing the indicator?

Several forest-ecosystem processes influence the productivity, and subsequently the carbon storage of a forest. The cumulative effects of different natural disturbances, decomposition, land uses, and human activities at the landscape scale have a major

influence on the net change in forest carbon. Fire suppression, agricultural land-abandonment, and plantation forestry often yield forests that are carbon sinks in the short term. Conversely, widespread natural disturbances such as fire and insect outbreaks can create forests that are net sources of carbon, an issue that adds great uncertainty to the future contribution of Canadian forests to the global carbon cycle (Goodale et al., 2002; Bond-Lamberty et al., 2007; Kurz et al., 2008).

- 3.4. Is the indicator largely unrelated to any other, as described by the linkages assessment and evaluation of key determinants? If so, and the indicator was defined as uninfluenced by climate change in the independent assessment, then it can be placed in category one.

Indicator 4.1.1 is influenced by climate change and is highly related to other indicators in the C&I framework and to external determinants of change. We do not recommend assigning it to category one.

- 3.5. Do the indirect effects of climate change via the linkages with other indicators influence the indicator's ability to signal SFM, regardless of which category was assigned in the independent climate-change assessment?

The influence of climate change on forest-ecosystem carbon will occur both directly, through climate-induced changes in forest-ecosystem productivity and decomposition rates, and indirectly through changes in natural disturbance regimes (Dale et al., 2001; Schimel et al., 2001; McMahon et al., 2010).

- 3.6. If the indicator's ability to signal SFM progress remains the same under a changing climate, can we conclude no negative influence and leave it unchanged? These indicators can be placed in category two.

Not applicable, Indicator 4.1.1 will deteriorate in its ability to signal our progress towards SFM.

- 3.7. If the indicator's ability to signal SFM progress deteriorates when one assumes a changing climate, then what modifications are possible or warranted to improve its ability sufficiently for it to remain among the C&I-SFM? These indicators can be placed in category three.

The influence of climate change on tree physiology and subsequently on forest productivity will necessitate modification to the tools we use to measure the net changes in forest-ecosystem carbon and Indicator 4.1.1. These modifications to the core assumptions of carbon budget models can be seen as essentially external to the C&I framework, as they do not warrant change to the actual design of Indicator 4.1.1. However, we have still assigned

Indicator 4.1.1, and Indicator 4.1.2, to category three, *Modified Indicators*, to emphasise the need for addressing these issues in future C&I-SFM assessments.

- 3.8. If no modifications seem possible or warranted, are we ready to recommend abandonment of the indicator? These indicators can be placed in category four.

Not applicable.

- 3.9. If we recommend abandonment, can we identify any new and closely allied indicators that might suit our needs better under climate change? These indicators can be placed in category five.

Not applicable.

- 3.10. Have extant climate-change impacts made this indicator more pertinent to SFM (i.e. 2.3 and the mountain pine beetle)? These indicators can be placed in category five or considered for conversion from a supporting to a core indicator (where applicable).

Warming summer temperatures and a greater area disturbed by fire has been detected in Canada, and has been attributed to climate change (Gillet et al., 2004). Forest fire is a key driver of Canada's carbon balance, so these changes have strong implications for Indicator 4.1.1 (Bond-Lamberty et al., 2007). Changes in forest productivity have also already been observed in Canada (Braswell & Schimel, 1997; Zhou et al., 2001; Bunn & Goetz, 2006). These changes have been attributed to longer growing seasons and warmer temperatures, and are again highly pertinent to Indicator 4.1.1.

Given the review of the entire C&I framework in light of the changing climate, we may be able to discover new opportunities to improve our ability to monitor SFM in Canada, regardless of climate change. As such, we feel it is appropriate to address possible new opportunities in question 3.11.

- 3.11. How should the surviving indicator (the original, modified, or new) be modelled and monitored so that stronger SFM signals may be generated?

The modifications that we recommend for Indicator 4.1.1 actually address how it is modelled and monitored, rather than the design of the Indicator itself. The primary source of data for the assessment of Indicator 4.1.1 is through the use of carbon budget models, such as the Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3; Kurz et al., 2009). The changing climate will be a large factor in the capacity of models to determine whether forests are net sinks or sources of atmospheric carbon (Larocque et al., 2008). Current carbon budget models employ forest inventory and sample-plot data to empirically develop carbon-storage patterns and yield curves (Kurz et al., 2009). This

approach relies heavily on historical growth and yield patterns of forests that have developed in a stable climate. This reliance on historical patterns of stand development may prove detrimental to the efficacy of current carbon modelling techniques in the face of climate change.

A future consideration for the measurement of both Indicators 4.1.1 and 4.1.2 would be to consider refining the Indicators so that they isolate and track only forest carbon fluxes caused by human management. This may provide a stronger signal of progress towards SFM as it relates to carbon, though this is not the focus of these evaluations.

3.12. Does this indicator track an entity whose relationship with climate is regionally variable?

The influence of climate change on forest-ecosystem carbon will be highly variable between Canada's terrestrial ecozones.

INDICATOR 4.1.2 FOREST ECOSYSTEM CARBON STORAGE BY FOREST TYPE AND AGE CLASS

1. Linkages Assessment

Table 1.1. Indicators influencing Indicator 4.1.2.

Indicator 4.1.2	Influencing Indicators
First order positive	2.1, 2.2, 2.5, and 3.1
First order negative	1.2.2, 1.2.3, 1.2.4, 2.3, 2.4, 3.3, 5.3.1, and 5.3.2
First order bi-directional	1.1.1, 1.1.2, 6.4.2, and 6.5.4

Table 1.2. Indicators influenced by Indicator 4.1.2.

Indicator 4.1.2	Influenced Indicators
First order positive	None
First order negative	None
First order bi-directional	1.2.1, 1.2.2, 1.2.3, 4.1.1, and 6.5.4

- 1.1. Which indicators are influencing and influenced directly (first-order interactions) by the indicator in question? Is the indicator more of a driver of change in other indicators, or being driven by other indicators?

Indicator 4.1.2 influences five other indicators, the majority of which are within Element 1.2. It is influenced by 16 indicators, from all Criteria excepting Criterion 4. Indicator 4.1.2 is a condition/response indicator, and is therefore much more influenced by other indicators than it is a driver of change.

- 1.2. List the indicators described as ‘relevant indicators under other criteria’ in the 2003 C&I-SFM. Is there any conflict with the interactions described in the matrix?

Forest ecosystem carbon stored in various types and age classes is very closely related to the type, age, and area of the forests in Canada, so Indicators 1.1.1, 2.2, 2.3, and 3.3 are naturally described as highly relevant to Indicator 4.1.2. This depiction corresponds with the findings in the interaction matrix.

- 1.3. Are there any overlaps or gaps in the relationship with indicators defined in Eddington and colleague’s (2009) report?

Within the FFEI indicator set, Indicator 13 *Ecosystem Productivity* from the *Biodiversity* category is probably the most related to Indicator 4.1.2, though the emphasis is more on wood volume than ecosystem carbon. Eddington and colleagues (2009) do describe ‘sink versus source’ determination as highly relevant in light of climate change, and of course the carbon uptake and storage potential of a forest is closely linked with forest ecosystem productivity.

2. Independent Climate-Change Assessment

- 2.1. Provide in detail, a qualitative description of what are the expected direct effects of climate change on the indicator, using a broad representation from the literature.

Forest-ecosystem carbon is stored in the living biomass of forests, both above and below ground, and dead organic matter, such as snags, litter, and coarse woody debris, of forests, as well as in the soil itself. In fact, soil carbon is believed to store an estimated 82% of forest ecosystem carbon in Canada (CCFM, 2006), but is far less dynamic than aboveground living forest biomass, which harbours the most attention in the discussion of forest carbon sinks and sources.

Accounting for forest-ecosystem carbon is a challenging task that is usually accomplished using simulation models that rely on established relationships in forest-carbon dynamics determined from forest inventories and sample plot data (MacLean et al., 2010). One prominent example is the Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3; Kurz et al., 2009). Carbon accounting has become a widespread and complex discipline, gaining popularity with policy-makers and governments because of the recognized potential of forests to mitigate climate change as carbon sinks in international agreements like UNFCCC and the Kyoto Protocol, using methodologies that have been internationally established by the IPCC (IPCC, 2003; Kurz et al., 2009).

It is a commonly held belief that climate change will benefit the net primary productivity of terrestrial biomes, and may in fact lead to an increase in the productivity of forests ecosystems (Schimel et al., 2001; Williamson et al., 2009; Friend, 2010). This is because climate warming will favour the metabolic processes of trees, such as photosynthesis, and cause a lengthening of the growing season when trees are metabolically active (Norby et al., 2005; McMahon et al., 2010). Moreover, the elevated concentration of atmospheric CO₂ is predicted to increase the water-use efficiency and subsequently the productivity of trees through the process of carbon fertilization (Friend, 2010). However, the magnitude and regional variability of these changes are highly uncertain, with many other factors influencing them, like seasonal variability of precipitation and moisture availability and alterations in natural disturbance regimes. Climate change may also influence the dead organic matter carbon pool through altered decay rates caused by changes in soil moisture and temperature (Stinson et al., 2011).

The anticipated increase in natural-disturbance frequency and magnitude have ramifications for forest-ecosystem carbon budgets, and may be the final determinant of whether a forest is a source or sink of atmospheric carbon (Kurz et al., 2008; Slaney et al., 2009). Kurz and colleagues (2008) illustrated the major loss of carbon uptake potential and future emissions from decaying trees caused by the mountain pine beetle (*Dendroctonus ponderosae*) epidemic in western Canada. Fire is also a major emitter of forest carbon when large quantities of stored carbon are burned and released to the atmosphere, and is also anticipated to increase in frequency and severity (Flannigan et al., 2009).

- 2.2. Given expected changes in Canada's climate, describe if and how the indicator's ability to signal progress towards SFM remains unchanged.

As with the large majority of biophysical state indicators in the C&I framework, the ability of Indicator 4.1.2 to signal SFM progress will be altered under climate change.

- 2.3. If an indicator's ability to signal progress towards SFM will be changed, describe if and how the indicator may become worse or better at signalling SFM progress.

Climate change has a strong potential to influence the amount of carbon in various forest types and age classes. This obscures many important characteristics of Indicator 4.1.2, including its predictability, responsiveness, and relevance. The measurement of the total carbon stored in above and below ground living biomass, dead organic matter, and forest soils is already recognized as a difficult and uncertain task (MacLean et al., 2010). Indicator 4.1.2, along with Indicator 4.1.1, may represent one of the rare instances where the measurability of the Indicator deteriorates under climate change. This is because of the invalidation of some of the assumptions around the core relationships between carbon pools, caused by changes in the photosynthetic rates and productivity of trees and in the decomposition rates of dead organic matter (Verburg, 2005). Furthermore, the unpredictability of changing natural disturbance regimes will have severe consequences for forest ecosystem carbon storage.

Climate change also significantly influences the relevance of indicators in Criterion 4, including Indicator 4.1.2, because of the growing recognition of the forests' potential to sequester and store atmospheric carbon and mitigate climate change. With the development of our knowledge around the drivers of human-induced climate change over the past decades and the formation of international agreements like the Kyoto Protocol and UNFCCC, we have developed new values associated with forest carbon and the global carbon cycle.

3. Integrated Climate-Change Assessment

- 3.1. What are the key determinants of the indicator (i.e. what causes it to change when it does change);
- a) Among other indicators in the C&I framework?
 - **The key determinants of Indicator 4.1.2 are 1.1.1, 1.1.2, and 2.1, as they pertain directly to the different types and age classes of forests and the biomass of trees.**
 - **Natural disturbances and timber harvests are another key determinant of forest ecosystem carbon, as represented primarily by Indicator 2.3, but also by Indicators 1.2.4, 3.3, 5.3.1, and 5.3.2.**

- b) Among determinants not within the C&I framework?
 - **Indicator 4.1.2 includes the carbon stored in dead organic matter and soil, as well as that in living biomass pools, so there will be many determining factors not within the C&I framework, such as atmospheric carbon fluxes, biomass decay, slow acting geomorphologic processes, and of course climate.**
- 3.2. For what other entities is this indicator a key determinant (i.e. when it changes, what other indicators are influenced to change);
- a) Among other indicators in the C&I framework?
 - **Indicator 4.1.2 is partially a determinant of forest habitat and therefore of forest-associated species tracked by Indicators 1.2.1, 1.2.2, and 1.2.3.**
 - b) Among determinants not within the C&I framework?
 - **The most noteworthy process for which Indicator 4.1.2 is a determinant is the global carbon cycle, in which the forest living biomass, dead biomass, and soil are major pools of carbon. Therefore, Indicator 4.1.2 is also a driver and partial determinant of climate.**
- 3.3. To what degree can we now, on the basis of extant knowledge, establish how the key determinants interact cumulatively in influencing the indicator?

The carbon that is sequestered and stored in the various types and age classes of forest ecosystems varies widely, with younger, fast-growing stands sequestering much more atmospheric carbon, and older, slow-growing stands storing far more carbon in living biomass. Total carbon storage in forest ecosystems across all forest types and structures is the cumulative result of many processes in addition to age-dependent growth and biomass accumulation, ranging from natural disturbances like fire and insect outbreaks to forest management and land-use changes.

This cumulative interaction of different determinants not only influences stand-level variations in carbon storage, but at the landscape scale can determine the net change in forest carbon. For example, in a shorter time frame, fire suppression, agricultural land-abandonment, and the establishment of intensely managed plantations can yield a situation where forests are a powerful sink of atmospheric carbon. Alternatively, a particularly severe fire season or forest insect epidemic will cause the release of vast amounts of forest carbon to the atmosphere, often making the determining whether forests are carbon sinks or sources (Goodale et al., 2002; Bond-Lamberty et al., 2007; Kurz et al., 2008).

- 3.4. Is the indicator largely unrelated to any other, as described by the linkages assessment and evaluation of key determinants? If so, and the indicator was defined as uninfluenced by climate change in the independent assessment, then it can be placed in category one.

Indicator 4.1.2 is related to many other indicators within the C&I framework, but more so to those that are influencing it. We do not recommend assigning it to category one.

- 3.5. Do the indirect effects of climate change via the linkages with other indicators influence the indicator's ability to signal SFM, regardless of which category was assigned in the independent climate-change assessment?

The influence of climate change on forest productivity and Indicator 2.1 will have implications for the rate at which atmospheric carbon is sequestered and stored. Anticipated increases in forest productivity and decomposition rates in the warming climate could potentially favour more rapid carbon sequestration. However, the effects of climate change on natural disturbance regimes, and indirectly on timber harvest patterns, tracked by Indicators 2.3 and 5.3.1, will be highly consequential for the amount of carbon that is stored and emitted from forest ecosystems.

- 3.6. If the indicator's ability to signal SFM progress remains the same under a changing climate, can we conclude no negative influence and leave it unchanged? These indicators can be placed in category two.

The ability of Indicator 4.1.2 to signal SFM progress will be diminished because of a decline in its predictability and measurability. We do not recommend assigning it to category two.

- 3.7. If the indicator's ability to signal SFM progress deteriorates when one assumes a changing climate, then what modifications are possible or warranted to improve its ability sufficiently for it to remain among the C&I-SFM? These indicators can be placed in category three.

Indicator 4.1.2 will require modification to the modelling tools used to measure forest ecosystem carbon, not to the design of the Indicator itself. The challenges in accounting for forest-ecosystem carbon have long been recognized, but they have been further obscured by the complexities introduced by climate change. Adapting the core assumptions of carbon budget models to address the climate-induced changes in forest-carbon dynamics entail modifications that are essentially external to the C&I framework. However, we have still assigned Indicator 4.1.2, and Indicator 4.1.1, to category three, *Modified Indicators*, to emphasise the need for addressing these issues in future C&I-SFM assessments.

- 3.8. If no modifications seem possible or warranted, are we ready to recommend abandonment of the indicator? These indicators can be placed in category four.

Not applicable.

- 3.9. If we recommend abandonment, can we identify any new and closely allied indicators that might suit our needs better under climate change? These indicators can be placed in category five.

Not applicable.

- 3.10. Have extant climate-change impacts made this indicator more pertinent to SFM (i.e. 2.3 and the mountain pine beetle)? These indicators can be placed in category five or considered for conversion from a supporting to a core indicator (where applicable).

Extant examples of the two major sources of climate-change influence on Indicator 4.1.2 can be found within Canada. Temperature is the most important determinant of wildfire in Canada, and climate-warming has been attributed with the observed increases in the extent of recent fires (Gillet et al., 2004; Flannigan et al., 2009). Changes in the length of the growing season and rises in temperature, as well as subsequently documented responses of forest productivity, have also been observed, mainly in Canada's northern regions (Braswell & Schimel, 1997; Zhou et al., 2001; Bunn & Goetz, 2006).

- 3.11. How should the surviving indicator (the original, modified, or new) be modelled and monitored so that stronger SFM signals may be generated?

The modifications that we recommend for Indicator 4.1.1 refer entirely to how it is modelled and monitored. Process-based, simulation models are a major component in predicting the effects of climate change on forest-ecosystem carbon cycles (MacLean et al., 2010). The changing climate will influence forest productivity and composition and will be a major factor in the capacity of models to determine whether forests are sinks or sources of carbon (Larocque et al., 2008). For example, current forest inventories and sample-plot data are used to empirically develop carbon-storage patterns and yield curves (Kurz et al., 2009), and therefore rely heavily on historical growth and yield patterns of forests that have developed in a stable climate. This reliance on historical patterns of stand development may prove detrimental to the efficacy of current carbon modelling techniques in a time of climate instability.

A future consideration for the measurement of both Indicators 4.1.1 and 4.1.2 would be to consider refining the Indicators so that they isolate and track only forest carbon fluxes caused by human management. This may provide a stronger signal of progress towards SFM as it relates to carbon, though this is not the focus of these evaluations.

3.12. Does this indicator track an entity whose relationship with climate is regionally variable?

The influence of climate change on forest-ecosystem carbon storage in different forest types and age classes will vary across ecozones.

INDICATOR 4.1.3 NET CHANGE IN FOREST PRODUCTS CARBON

1. Linkages Assessment

Table 1.1. Indicators influencing Indicator 4.1.3.

Indicator 4.1.3	Influencing Indicators
First order positive	5.3.1 and 5.3.2
First order negative	None
First order bi-directional	5.1.3

Table 1.2. Indicators influenced by Indicator 4.1.3.

Indicator 4.1.3	Influenced Indicators
First order positive	4.1.4
First order negative	None
First order bi-directional	None

- 1.1. Which indicators are influencing and influenced directly (first-order interactions) by the indicator in question? Is the indicator more of a driver of change in other indicators, or being driven by other indicators?

Indicator 4.1.3 is influenced by three other indicators directly, all from Criterion 5. Indicator 4.1.4 is the only indicator that is influenced by it. Indicator 4.1.3 is not highly linked to other indicators within the C&I framework, and is marginally less of a driver of change than it is influenced by other indicators.

- 1.2. List the indicators described as ‘relevant indicators under other criteria’ in the 2003 C&I-SFM. Is there any conflict with the interactions described in the matrix?

The 2003 C&I-SFM guide focuses primarily on indicators that are relevant to the uptake, storage, and balance of forest ecosystem carbon. There is no mention of the role of other indicators in forest products carbon, or the relevance of forest product carbon cycling to other indicators.

- 1.3. Are there any overlaps or gaps in the relationship with indicators defined in Eddington and colleague’s (2009) report?

The FFEI project is focused on monitoring key species and ecological processes in order to signal and anticipate the response of forest and rangeland to climate change. There is no inclusion of the socio-economic dimension of SFM, so there is no overlap between the C&I framework and the Eddington et al. (2009) report.

2. Independent Climate-Change Assessment

- 2.1. Provide in detail, a qualitative description of what are the expected direct effects of climate change on the indicator, using a broad representation from the literature.

There is no major direct source of influence for climate change on the net change in forest products carbon. However, forest products carbon and the substitution of non-renewable materials for forest products are relevant to climate change and SFM. Carbon that is stored in forest products, whether it is for a relatively short period in paper products or for a longer time in construction material and furniture, is growing in recognition as an important pool of carbon within the forest sector (Apps et al., 1999; Hennigar et al., 2008; MacLean et al., 2010). The recent proliferation of forest-management initiatives for maximizing carbon sequestration and storage has been driven by the acknowledgment of a forests' capacity to mitigate human-induced climate change (IPCC, 2003). However, carbon stored in forest products is not yet completely recognized in the UNFCCC or Kyoto Protocol, though an informal agreement on this was reached in Cancun, 2011. Despite this, it is becoming increasingly acknowledged that the entire life cycle of forest carbon, from seed to landfill, and product substitutions need to be addressed in the forest sector's contribution to global carbon cycles (Hennigar et al., 2008).

Current methods for carbon accounting consider all carbon in a harvested stand to be lost as emissions at the time of harvest, under the assumption that new forest products will only replace existing pools (MacLean et al., 2010). Forest product carbon pools, while highly dependent on the accounting methods and on physical processes like the decay of products in and out of landfills, have been proven to be potential sinks of atmospheric carbon (Kurz et al., 1995; Apps et al., 1999; Canadell & Raupach, 2008). Anthropogenic carbon emissions can also be avoided through the sustainable substitution of emission-intensive materials with renewable wood products. However, relatively few research efforts have been focusing on optimizing the carbon storage of all carbon pools in the forest sector, including forest products and emissions reductions from product substitution (Hennigar et al., 2008; Neilson et al., 2008).

- 2.2. Given expected changes in Canada's climate, describe if and how the indicator's ability to signal progress towards SFM remains unchanged.

There is little chance of direct climatic influence on the net change in forest products carbon, except for a potential increase in the decomposition rates of some forest product carbon pools in the elevated temperatures (Verburg, 2005). Any decline in indicator predictability will be marginal.

Indicator 4.1.3 is one of the rare cases where the Indicator's relationship with climate change is that of a potential climate driver and tool for mitigation, as opposed to being itself influenced by climatic change. This is owed to the long-term storage of carbon in forest products and to emissions prevented by product substitution. The relevance of Indicator 4.1.3 to SFM progress will therefore increase under climate change, as it does for

other indicators in Criterion 4. However, carbon accounting methods will need improvement if we are to comprehend the full role of forest-products carbon in global cycles.

- 2.3. If an indicator's ability to signal progress towards SFM will be changed, describe if and how the indicator may become worse or better at signalling SFM progress.

Indicator 4.1.3 will not worsen in its ability to signal SFM progress. However, the Indicator does become more relevant to SFM under climate change. Indicator 4.1.3 is one of several indicators that track entities which are climate drivers, and should possibly be earmarked for a separate action-related category of indicators.

3. Integrated Climate-Change Assessment

- 3.1. What are the key determinants of the indicator (i.e. what causes it to change when it does change);

- a) Among other indicators in the C&I framework?
 - **The flux of carbon from the living biomass pool to the forest products pool is largely determined by Indicator 5.3.1, and to a lesser extent, Indicator 5.3.2.**
 - **The forest product carbon stock calculated in the 2005 C&I-SFM assessment is a factor of commodity consumption (domestic production + imports – exports; CCFM, 2006). Therefore, Indicator 5.1.3 is a key determinant.**

- b) Among determinants not within the C&I framework?
 - **Consumer preference for different forest products, product longevity, and decay rates are all external determinants of Indicator 4.1.3.**
 - **The approach and model design for the budgeting/accounting of forest product carbon pools and the availability of data all have a major role in the perceived net change in carbon tracked by Indicator 4.1.3.**
 - **Economic cycles both in Canada and abroad are important determinant of Indicator 4.1.3, as they determine demand for forest products.**

- 3.2. For what other entities is this indicator a key determinant (i.e. when it changes, what other indicators are influenced to change);

- a) Among other indicators in the C&I framework?

- **Forest product carbon stocks are a determinant of emissions in the forest sector and Indicator 4.1.4, both through the production of wood products and the carbon emissions from decaying forest products in landfills.**

b) Among determinants not within the C&I framework?

- **Due to the potential for forest products to act as sinks of atmospheric carbon, they can be described as climate drivers, so the net change in forest products carbon is a determinant of climate.**

3.3. To what degree can we now, on the basis of extant knowledge, establish how the key determinants interact cumulatively in influencing the indicator?

The net change in forest product carbon is by nature a cumulative process. It is influenced by the harvest and manufacturing of forest products, which is driven by production and consumption. Forest products carbon fluxes are also cumulatively influenced by physical processes, such as emission rates, primary decay rates, and decay rates in landfills (Hennigar et al., 2008). Climate change is far more likely to significantly influence the former than the latter, as climate change is predicted to affect global forest product markets (Perez-Garcia et al., 2002).

3.4. Is the indicator largely unrelated to any other, as described by the linkages assessment and evaluation of key determinants? If so, and the indicator was defined as uninfluenced by climate change in the independent assessment, then it can be placed in category one.

Indicator 4.1.3 is relatively unrelated to other indicators within the C&I framework. However, the increase in its relevance under climate change preclude assignment to category one.

3.5. Do the indirect effects of climate change via the linkages with other indicators influence the indicator's ability to signal SFM, regardless of which category was assigned in the independent climate-change assessment?

The potential impacts of climate change on forest ecosystems and their disturbance regimes may have some consequence for Indicator 4.1.3, but not to the degree that its SFM signal is diminished; see Question 3.10.

3.6. If the indicator's ability to signal SFM progress remains the same under a changing climate, can we conclude no negative influence and leave it unchanged? These indicators can be placed in category two.

The Indicator does not remain unchanged in its ability to signal SFM progress. However, rather than modify this relatively simple indicator, we chose to instead create a new indicator in response to the increase in relevance.

- 3.7. If the indicator's ability to signal SFM progress deteriorates when one assumes a changing climate, then what modifications are possible or warranted to improve its ability sufficiently for it to remain among the C&I-SFM? These indicators can be placed in category three.

Not applicable.

- 3.8. If no modifications seem possible or warranted, are we ready to recommend abandonment of the indicator? These indicators can be placed in category four.

Not applicable.

- 3.9. If we recommend abandonment, can we identify any new and closely allied indicators that might suit our needs better under climate change? Are there any other reasons for the creation of an additional indicator? These indicators can be placed in category five.

While we did not abandon the original Indicator, we did elect to create an additional indicator in response the increasing relevance of carbon emissions under climate change. We therefore recommend *Carbon Emissions Avoided through Product Substitution* as a new indicator in Criterion 4.

- 3.10. Have extant climate-change impacts made this indicator more pertinent to SFM (i.e. 2.3 and the mountain pine beetle)? These indicators can be placed in category five or considered for conversion from a supporting to a core indicator (where applicable).

Several indirect examples of climate-change impacts may be seen as pertinent to the net change in forest products carbon. The salvage harvests that are necessitated by more frequent and severe disturbance events, such as those arising from the adjusted allowable annual cut in British Columbia in response to the mountain pine beetle (*Dendroctonus ponderosae*) epidemic, certainly have some influence on the carbon balance of the regional forest product carbon pool (Pederson, 2004; Spittlehouse, 2005). However, given both the current and potential future approaches to measuring Indicator 4.1.3, we are confident that this will not compromise the SFM signal that is generated to any great degree.

- 3.11. How should the surviving indicator (the original, modified, or new) be modelled and monitored so that stronger SFM signals may be generated?

The current method for measuring the forest products carbon stock change is commodity consumption minus emissions, where commodity consumption is equal to domestic production plus imports minus exports, and emissions are equal to emissions from the current-year production plus emissions from products already in long-term storage (CCFM, 2006).

Modelling techniques for the carbon budget of forest products are a developing science, which are striving towards accounting for carbon in the entire life cycle of forest products to get an accurate picture of forest-sector carbon cycles (Hennigar et al., 2008). This emphasizes the need to harmonize measurement methodologies with Indicators 4.1.1 and 4.1.2. Furthermore, emissions reductions that are incurred from product substitution also need to be addressed, as recommended in this evaluation. It will also be important to examine what we classify as forest products, with the growing relevance of bioproducts, biomaterials, and other forest-derived goods under climate change.

3.12. Does this indicator track an entity whose relationship with climate is regionally variable?

The regional variability of climate change does not greatly influence the net change in forest products carbon.

INDICATOR 4.1.4 FOREST SECTOR CARBON EMISSIONS

1. Linkages Assessment

Table 1.1. Indicators influencing Indicator 4.1.4.

Indicator 4.1.4	Influencing Indicators
First order positive	4.1.3, 5.1.3, 5.3.1, and 5.3.2
First order negative	None
First order bi-directional	None

Table 1.2. Indicators influenced by Indicator 4.1.4.

Indicator 4.1.4	Influenced Indicators
First order positive	2.4
First order negative	None
First order bi-directional	None

- 1.1. Which indicators are influencing and influenced directly (first-order interactions) by the indicator in question? Is the indicator more of a driver of change in other indicators, or being driven by other indicators?

Indicator 4.1.4 is influenced by four other indicators directly, primarily from Criterion 5, but also by Indicator 4.1.3. Only one other indicator is influenced by it, which is the area of forest disturbed by ozone and acid rain (Indicator 2.4). Indicator 4.1.4 is less of a driver of change than it is driven to change by other indicators. However, it is not highly linked with other indicators within the C&I framework.

- 1.2. List the indicators described as ‘relevant indicators under other criteria’ in the 2003 C&I-SFM. Is there any conflict with the interactions described in the matrix?

The 2003 C&I-SFM report focuses primarily on indicators that are relevant to the uptake, storage, and balance of forest-ecosystem carbon. There is no mention of the role of other indicators in forest-sector carbon emissions, or the relevance of carbon emissions to other indicators.

- 1.3. Are there any overlaps or gaps in the relationship with indicators defined in Eddington and colleague’s (2009) report?

The FFEI project is focused on monitoring key species and ecological processes in order to signal and anticipate the response of forest and rangeland to climate change. There is no inclusion of the socio-economic dimension of SFM, so there is no overlap between the C&I framework and the Eddington et al. (2009) report.

2. Independent Climate-Change Assessment

- 2.1. Provide in detail, a qualitative description of what are the expected direct effects of climate change on the indicator, using a broad representation from the literature.

The emission of greenhouse gases, primarily carbon dioxide (CO₂), from burning fossil fuels is the primary cause of the recent and predicted future changes in climate (IPCC, 2007). The vast majority of these emissions come from the electricity and petroleum industries and from transportation (Matin et al., 2004). While forests and forest products can be sinks of atmospheric carbon (MacLean et al., 2010), the forest sector is also a source of carbon and other greenhouse gases, albeit a relatively small one (Saddler, 2002; Matin et al., 2004).

Indicator 4.1.4 is one of the very few among the 46 indicators of the C&I framework that specifically addresses climate change in its goal description, which is to monitor the contribution of the forest sector to Canadian greenhouse gas emissions (CCFM, 2006). In the assessment of Indicator 4.1.4, CO₂, methane (CH₄), and nitrous oxide (N₂O) emissions, with the latter two converted to CO₂ equivalents, are reported from the combined logging, pulp and paper manufacturing, and wood products manufacturing industries of the forest sector (CCFM, 2006).

There will be no major direct effects of climate change on forest sector carbon emissions. However, it is highly likely that the indirect effects of climate change may lead to a reduction in forest-sector emissions. There are many policy tools and international agreements like the UNFCCC that target the reduction of greenhouse gas emissions in Canada. These policy tools can range from traditional or market-based regulations to government investment in efficiency, infrastructure, and technology development (Demerse & Bramley, 2008). In response to the recent attention on greenhouse gases, the forest sector in Canada is believed to have reduced its direct emissions by an estimated 44% between 1990 and 2007, while simultaneously increasing production by 20% (Johnston et al., 2010).

- 2.2. Given expected changes in Canada's climate, describe if and how the indicator's ability to signal progress towards SFM remains unchanged.

The ability of Indicator 4.1.4 to signal SFM progress may be altered under climate change, though likely not to any large degree.

- 2.3. If an indicator's ability to signal progress towards SFM will be changed, describe if and how the indicator may become worse or better at signalling SFM progress.

Indicator 4.1.4 will increase in relevance under climate change, as with the other Indicators within Criterion 4, because of the potential for forests and forest products to mitigate climate change and, in the case of forest-sector emissions, contribute to the climate forcing

of anthropogenic greenhouse gas emissions. However, the future uncertainty around the magnitude and rate of climate change and society's response, namely the employment of policy tools for emissions reductions, may to some degree confound the predictability of Indicator 4.1.4.

3. Integrated Climate-Change Assessment

3.1. What are the key determinants of the indicator (i.e. what causes it to change when it does change);

- a) Among other indicators in the C&I framework?
 - **Forests-sector carbon emissions are closely linked to the production and manufacturing of timber products, and thus determined by Indicator 5.1.3.**
 - **Carbon emissions also occur during operations, making Indicator 5.3.1, and to a lesser degree Indicator 5.3.2, key determinants.**
 - **As discussed in the previous evaluation, forest products and Indicator 4.1.3 are determinants of forest sector carbon emissions.**

b) Among determinants not within the C&I framework?

- **Climate-change policies and international agreements addressing global environment change and greenhouse gas emissions are all potential determinants of Canadian emission rates, including those from the forest sector.**
- **The transportation subsector of the forest sector, and the emissions associated with it, is external to the C&I framework (CCFM, 2006).**

3.2. For what other entities is this indicator a key determinant (i.e. when it changes, what other indicators are influenced to change);

- a) Among other indicators in the C&I framework?
 - **Emissions from the combustion of fossil fuels in the forest sector can be a source of acid deposition and tropospheric ozone, but again a relatively small one in comparison with other sources. Consequently, Indicator 4.1.4 is a determinant of Indicator 2.4.**

b) Among determinants not within the C&I framework?

- **Greenhouse gas emissions from the forest sector contribute to anthropogenic climate change, though to a considerably lesser degree than other sectors of the Canadian economy.**

3.3. To what degree can we now, on the basis of extant knowledge, establish how the key determinants interact cumulatively in influencing the indicator?

The cumulative interactions of the determinants of forest-sector carbon emissions are not nearly as elusive and complex as with some other indicators. Greenhouse gas emissions that are measured under Indicator 4.1.4 are all directly emitted from the various forest subsectors, though the emission rates will be dependent on technology and production rates. However, these greenhouse gases, once emitted to the atmosphere, clearly cause complex cumulative effects on global climate (IPCC, 2007).

3.4. Is the indicator largely unrelated to any other, as described by the linkages assessment and evaluation of key determinants? If so, and the indicator was defined as uninfluenced by climate change in the independent assessment, then it can be placed in category one.

Indicator 4.1.4 is largely unrelated to other indicators, in relative terms. However, due to the change in indicator relevance and predictability, we do not recommend assigning it to category one.

3.5. Do the indirect effects of climate change via the linkages with other indicators influence the indicator's ability to signal SFM, regardless of which category was assigned in the independent climate-change assessment?

The formation and implementation of policy tools to reduce greenhouse gas emissions and mitigate climate change have the potential to reduce emission rates from the forest sector (Demerse & Bramley, 2008). However, there is no reason to assume that this decline in predictability will overly obscure the SFM signal of Indicator 4.1.4, nor will the increase in relevance. We therefore recommend assigning it to category two, *Unmodified Indicators*.

3.6. If the indicator's ability to signal SFM progress remains the same under a changing climate, can we conclude no negative influence and leave it unchanged? These indicators can be placed in category two.

Not applicable.

3.7. If the indicator's ability to signal SFM progress deteriorates when one assumes a changing climate, then what modifications are possible or warranted to improve its ability

sufficiently for it to remain among the C&I-SFM? These indicators can be placed in category three.

Not applicable.

- 3.8. If no modifications seem possible or warranted, are we ready to recommend abandonment of the indicator? These indicators can be placed in category four.

Not applicable.

- 3.9. If we recommend abandonment, can we identify any new and closely allied indicators that might suit our needs better under climate change? Are there any other reasons for the creation of an additional indicator? These indicators can be placed in category five.

Not applicable.

- 3.10. Have extant climate-change impacts made this indicator more pertinent to SFM (i.e. 2.3 and the mountain pine beetle)? These indicators can be placed in category five or considered for conversion from a supporting to a core indicator (where applicable).

There are potential examples of increasing carbon emissions from the forest sector due to climate change. However, they are all attributable to direct emissions from forest ecosystems because of recent severe insect outbreaks and fires (Kurz et al., 2008; Flannigan et al., 2009). Extant examples of changes in the emission rates of CO₂, CH₄, or N₂O from logging, pulp and paper manufacturing, or wood products manufacturing resulting from climate change, though possible, have not been documented. This would be exceedingly difficult if not infeasible to track.

- 3.11. How should the surviving indicator (the original, modified, or new) be modelled and monitored so that stronger SFM signals may be generated?

Emission rates from the Canadian forest sector are compiled by Natural Resources Canada, with data from Environment Canada and Statistics Canada (CCFM, 2006). There is no foreseeable mechanism in which climate change could influence the feasibility or measurability of Indicator 4.1.4.

- 3.12. Does this indicator track an entity whose relationship with climate is regionally variable?

The regional variability of climate change does not significantly influence forest sector carbon emissions or Indicator 4.1.4.

INDICATOR 5.1.1 CONTRIBUTION OF TIMBER PRODUCTS TO THE GROSS DOMESTIC PRODUCT

1. Linkages Assessment

Table 1.1. Indicators influencing Indicator 5.1.1.

Indicator 5.1.1	Influencing Indicators
First order positive	5.1.2, 5.1.3, and 5.3.1
First order negative	None
First order bi-directional	None

Table 1.2. Indicators influenced by Indicator 5.1.1.

Indicator 5.1.1	Influenced Indicators
First order positive	5.3.3
First order negative	None
First order bi-directional	None

- 1.1. Which indicators are influencing and influenced directly (first-order interactions) by the indicator in question? Is the indicator more of a driver of change in other indicators, or being driven by other indicators?

Indicator 5.1.1 is influenced by three other indicators, all from Criterion 5. It only influences one other indicator within the framework, Indicator 5.3.3. Indicator 5.1.1 is an economic state indicator, so it is not a major driver of change, but rather driven to change by other economic indicators.

- 1.2. List the indicators described as ‘relevant indicators under other criteria’ in the 2003 C&I-SFM. Is there any conflict with the interactions described in the matrix?

The forest sector’s economic welfare and contribution to the Canadian economy is of course highly dependent on the condition, productivity, and diversity of forest ecosystems (i.e. Criteria 1 and 2). The economic benefits to society from forests are described as dependent on the area, type, age, and growing stock of forests, as monitored by Indicators 1.1.1, 1.1.2, and 2.1. Relationships of this nature would only be reflected in second-order interactions within the interaction matrix. For example, total growing stock (Indicator 2.1) is a key determinant of the annual harvest of timber (Indicator 5.3.1), which in turn influences the contribution of timber products to the gross domestic product (GDP). Indicators can often be highly relevant to another without a direct linkage between them.

- 1.3. Are there any overlaps or gaps in the relationship with indicators defined in Eddington and colleague’s (2009) report?

The FFEI project is focused on monitoring key species and ecological processes in order to signal and anticipate the response of forest and rangeland to climate change. There is no inclusion of the socio-economic dimension of SFM, so there is no overlap between the C&I framework and the Eddington et al. (2009) report.

2. Independent Climate-Change Assessment

- 2.1. Provide in detail, a qualitative description of what are the expected direct effects of climate change on the indicator, using a broad representation from the literature.

The goal of Indicator 5.1.1, in tandem with other indicators from Element 5.1, is to track the contribution of the forest sector to the Canadian economy. Climate change will influence forest ecosystems and the forest sector in a wide variety of ways (Johnston et al., 2010). The flow of timber products will fluctuate due to changes in quantity and quality of wood fibre, caused by changes in forest productivity and the area of forest affected by natural disturbances (Dale et al., 2001; Williamson et al., 2009), and changes in the types of timber products available due to shifting ranges of tree species and changes in forest composition (McKenney et al., 2007).

It is also held that global increases in timber supply will eventually cause a drop in prices and an increase in consumption of timber products (Perez-Garcia et al., 2002; Williamson et al., 2008). However, this is tremendously uncertain and variable across different nations and regions. For example, in drier boreal regions like northwestern Ontario, declines in precipitation rates and more frequent fires and insect outbreaks are expected to reduce the timber supply, while global increases in wood fibre, lower prices, and increases in production costs are expected to be severely detrimental to the forest sector of the region (Browne & Hunt, 2007). The contribution of timber products to the GDP of Canada will certainly vary in response to these diverse and complex impacts.

There is also a growing demand for more efficient and low-emission renewable energy sources. Forest biomass as a source for bioenergy generation is becoming increasingly recognized as a feasible and essentially carbon-neutral alternative to fossil fuels (Yemshanov & McKenney, 2008). Thus, there is a strong potential for a growing contribution of forest bioenergy products to the GDP under climate change.

- 2.2. Given expected changes in Canada's climate, describe if and how the indicator's ability to signal progress towards SFM remains unchanged.

Indicator 5.1.1 will be altered by climate change in its ability to signal SFM progress.

- 2.3. If an indicator's ability to signal progress towards SFM will be changed, describe if and how the indicator may become worse or better at signalling SFM progress.

The SFM signal that is generated by Indicator 5.1.1 will not be diminished to the point that it is no longer valid. It is easily measurable and conceptually easy to understand, so despite the aforementioned predictions of how climate change will influence the contribution of timber products to the GDP, we assume that the corresponding changes in the predictability of Indicator 5.1.1 will be minimal. However, the growing relevance of new timber-product subsectors to SFM, such as bioenergy products, may warrant inclusion into Indicator 5.1.1.

3. Integrated Climate-Change Assessment

3.1. What are the key determinants of the indicator (i.e. what causes it to change when it does change);

- a) Among other indicators in the C&I framework?
 - **Indicators 5.1.2, 5.1.3, and 5.3.1 all monitor the supply chain of timber products, which describes the capital-generating activities contributing to the GDP.**
- b) Among determinants not within the C&I framework?
 - **The total GDP, and of course contributions from other sectors of the Canadian economy will greatly influence the relative contribution of the forest sector. For example, the forest industry did expand between 1961 and 2004, but the total contribution to the GDP declined considerably because of the growth of other industries, like information technologies (CCFM, 2006).**
 - **Domestic and international demand for timber products is a key determinant of Indicator 5.1.1. The forest products sector is heavily influenced by foreign markets and international trade patterns, as Canada is a major exporter.**

3.2. For what other entities is this indicator a key determinant (i.e. when it changes, what other indicators are influenced to change);

- a) Among other indicators in the C&I framework?
 - **Indicator 5.1.1 is a partial determinant of the return on capital employed in forest products industries, which is tracked by Indicator 5.3.3.**
- b) Among determinants not within the C&I framework?

- **While the overall contribution of the forest sector to the GDP is relatively small, at approximately 3% (CCFM, 2006), it is still a partial determinant of the total Canadian economy and its welfare.**

3.3. To what degree can we now, on the basis of extant knowledge, establish how the key determinants interact cumulatively in influencing the indicator?

The total contribution of timber products to the GDP is the sum of all the subsector contributions that are measured, including wood industries, forestry services and logging, and pulp and allied industries. However, the complex, cumulative interactions of consumer demand, international trade and market stability, and of course the condition and productivity of forest ecosystems will ultimately determine the overall value of the timber products sector.

3.4. Is the indicator largely unrelated to any other, as described by the linkages assessment and evaluation of key determinants? If so, and the indicator was defined as uninfluenced by climate change in the independent assessment, then it can be placed in category one.

Indicator 5.1.1 is relatively unrelated to other indicators within the C&I framework. However, because of these interactions it is not entirely uninfluenced by climate change and therefore has not been assigned to category one.

3.5. Do the indirect effects of climate change via the linkages with other indicators influence the indicator's ability to signal SFM, regardless of which category was assigned in the independent climate-change assessment?

The influence of climate change on global supply and demand for timber products and the potential changes in Canadian exports (Williamson et al., 2008), as tracked by Indicator 5.1.3, will have major implications for the contribution of timber products to the GDP.

3.6. If the indicator's ability to signal SFM progress remains the same under a changing climate, can we conclude no negative influence and leave it unchanged? These indicators can be placed in category two.

The ability of Indicator 5.1.1 to signal SFM progress does not remain the same under climate change because of decline in the predictability. More importantly, there is potential for the relevance of Indicator 5.1.1 to increase.

3.7. If the indicator's ability to signal SFM progress deteriorates when one assumes a changing climate, then what modifications are possible or warranted to improve its ability

sufficiently for it to remain among the C&I-SFM? These indicators can be placed in category three.

We believe that the discussed changes in the SFM signal generated by Indicator 5.1.1 do not degrade it substantially because it is such as easily measured and understandable indicator. However, forest-biomass combustion for heat and electricity generation is growing in recognition as a ‘carbon neutral’ source of energy under climate change. We recommend including the contribution of bioenergy generated from forest biomass as one of the subsectors that is measured for its contribution to the GDP.

3.8. If no modifications seem possible or warranted, are we ready to recommend abandonment of the indicator? These indicators can be placed in category four.

Not applicable.

3.9. If we recommend abandonment, can we identify any new and closely allied indicators that might suit our needs better under climate change? Are there any other reasons for the creation of an additional indicator? These indicators can be placed in category five.

Not applicable.

3.10. Have extant climate-change impacts made this indicator more pertinent to SFM (i.e. 2.3 and the mountain pine beetle)? These indicators can be placed in category five or considered for conversion from a supporting to a core indicator (where applicable).

Bioenergy is recognized as having the greatest potential for renewable generating capacity (Bradley, 2006). Canada has already developed funding programs for the research and development of bioenergy initiatives from forest-derived woody biomass, such as the Forests 2020 Plantation Demonstration and Assessment initiative (Dominy et al., 2010).

3.11. How should the surviving indicator (the original, modified, or new) be modelled and monitored so that stronger SFM signals may be generated?

Data on the contributions of various sectors of the Canadian economy to the GDP are prominent economic statistics, which are collected by Statistics Canada. Climate change does not necessitate any changes to the monitoring approach for the forest subsectors measured in the 2005 C&I-SFM assessment. However, we do recommend that data on the contribution of the burgeoning forest-biomass subsector to the GDP be collected in future C&I-SFM assessments.

3.12. Does this indicator track an entity whose relationship with climate is regionally variable?

Indicator 5.1.1 measures contributions to the GDP, without addressing jurisdictional or regional differences in contributions, so the influence of climate change on Indicator 5.1.1 will not be spatially sensitive.

INDICATOR 5.1.2 VALUE OF SECONDARY MANUFACTURING OF TIMBER PRODUCTS PER VOLUME HARVESTED

1. Linkages Assessment

Table 1.1. Indicators influencing Indicator 5.1.2.

Indicator 5.1.2	Influencing Indicators
First order positive	5.1.3, 5.3.1, and 6.5.3
First order negative	None
First order bi-directional	None

Table 1.2. Indicators influenced by Indicator 5.1.2.

Indicator 5.1.2	Influenced Indicators
First order positive	5.1.1
First order negative	None
First order bi-directional	None

- 1.1. Which indicators are influencing and influenced directly (first-order interactions) by the indicator in question? Is the indicator more of a driver of change in other indicators, or being driven by other indicators?

Indicator 5.1.2 is influenced by three other indicators, which track the availability of primary manufactured products (Indicators 5.1.3 and 5.3.1) and investment in secondary manufacturing (Indicator 6.5.3). It influences only one other indicator, which is the contribution of timber products to the gross domestic product (Indicator 5.1.1). Indicator 5.1.2 is an economic state variable, and as such it is not a major driver of change.

- 1.2. List the indicators described as ‘relevant indicators under other criteria’ in the 2003 C&I-SFM. Is there any conflict with the interactions described in the matrix?

The secondary manufacturing of timber products and economic benefits they generate relies on the supply and input of solid wood products from primary manufacturing, which is fundamentally dependent on the condition, productivity, and diversity of forest ecosystems, as represented by Indicators 1.1.1, 1.1.2, and 2.1. These relevant relationships described in the 2003 C&I-SFM report would be reflected as second-order interactions in the interaction matrix.

- 1.3. Are there any overlaps or gaps in the relationship with indicators defined in Eddington and colleague’s (2009) report?

The FFEI project is focused on monitoring key species and ecological processes in order to signal and anticipate the response of forest and rangeland to climate change. There is no

inclusion of the socio-economic dimension of SFM, so there is no overlap between the C&I framework and the Eddington et al. (2009) report.

2. Independent Climate-Change Assessment

- 2.1. Provide in detail, a qualitative description of what are the expected direct effects of climate change on the indicator, using a broad representation from the literature.**

The global supply of wood fibre is increasing both currently, due to low-cost plantations in New Zealand, Chile, and Brazil (Spetic, 2009), and prospectively, due to the influence of climate change of terrestrial net primary productivity (Schimel et al., 2001). Canada will be faced with many challenges to maintain its level of production of primary forest products under climate change because of the biophysical impacts on forest ecosystems and the changing global market place (Perez-Garcia et al., 2002). Furthermore, the growing societal and regulatory pressure to maintain forest biodiversity coupled with the current state of Canada's operational forests resulting from historical exploitation dictate that we will not be able to maintain current or recent harvest levels in the future (Stennes et al., 2005).

Secondary manufacturing of solid wood products, frequently referred to as value-added processing, is a strategy to ensure that we obtain the maximum value per unit of wood fibre that is harvested in Canada (DeLong et al., 2007). Secondary manufacturing can also be an important generator of employment, especially in rural and forest-dependent communities (Stennes et al., 2005). Secondary manufacturing products are becoming an increasingly important contributor to the total economic value of the forest sector, and have in fact been expanding faster than the primary manufacturing industries (CCFM, 2006).

There is an inescapable link between the secondary manufacturing of timber products to both timber product markets and the health of forest ecosystems, both of which will be influenced by the changing climate (Perez-Garcia et al., 2002; Johnston et al., 2010). The supply of timber from forest ecosystems and the quality of that timber will be affected by changes in forest productivity and an increased frequency and severity of fires, insects and disease outbreaks, and windstorms (Dale et al., 2001; Williamson et al., 2009). Over the longer term, there will also likely be changes in the types of timber products available for secondary manufacturing because of climate-induced changes in tree-species distribution and forest composition (McKenney et al., 2007).

- 2.2. Given expected changes in Canada's climate, describe if and how the indicator's ability to signal progress towards SFM remains unchanged.**

As a condition/response indicator, it is highly likely that the predictability of Indicator 5.1.2 will decline due to climate change. However, the secondary manufacturing of timber products tracked by Indicator 5.1.2 is far enough removed from the intricate and uncertain effects of climate change on forest-ecosystem condition and productivity that its SFM signal

is not overly diminished in its responsiveness to agents of change and relevance to the greater context of timber product markets and SFM. The Indicator's linear dependence on the supply primary manufacturing products (Indicator 5.1.3) make fluctuations in this Indicator easily understandable, despite the likelihood that climate change will influence the flow of primary timber products.

2.3. If an indicator's ability to signal progress towards SFM will be changed, describe if and how the indicator may become worse or better at signalling SFM progress.

The predictability of Indicator 5.1.2 may decrease slightly because of climate change. However, the ability of Indicator 5.1.2 to signal our progress towards SFM will not significantly diminished.

3. Integrated Climate-Change Assessment

3.1. What are the key determinants of the indicator (i.e. what causes it to change when it does change);

a) Among other indicators in the C&I framework?

- **The most important determinant of Indicator 5.1.2 is Indicator 5.1.3, because secondary manufacturing relies on the input of primary manufacturing products.**
- **Indicator 5.1.2 is also dependent on the annual harvest of timber tracked by Indicator 5.3.1, both as an input into primary production and because the Indicator measures the value of secondary manufacturing per volume harvested.**
- **Investment in timber products industry research and development (Indicator 6.5.3) has a positive influence on secondary manufacturing and is therefore a determinant of Indicator 5.1.2.**

b) Among determinants not within the C&I framework?

- **The value of secondary manufacturing products is highly dependent on the strength of domestic and foreign markets, and Canada's ability to compete in them.**
- **Burdensome trade restrictions on the export of secondary manufacturing products to the United States and a few other foreign markets are an important determinant of Indicator 5.1.2 (Stennes et al., 2005).**
- **Policy tools to promote secondary manufacturing in the various jurisdictions can have influence on the value added from secondary manufacturing and are a determinant of Indicator 5.1.2.**

3.2. For what other entities is this indicator a key determinant (i.e. when it changes, what other indicators are influenced to change);

a) Among other indicators in the C&I framework?

- **Employment rates are influenced by secondary manufacturing, making Indicator 5.1.2 a determinant of Indicators 5.3.5 and 6.3.3. While this was not a first-order interaction in the linkages assessment, it is still noteworthy.**
- **Though highly dependent on the locality of secondary manufacturing and production, forest-dependent community well-being (Element 6.3) is frequently seen to benefit from those activities.**

b) Among determinants not within the C&I framework?

- **The value added by the secondary manufacturing of timber products is believed to strongly profit the economic sustainability of the forest sector. The secondary manufacturing industry will certainly influence other areas of the economy and of communities where manufacturing occurs in ways that are external to SFM and the C&I framework.**

3.3. To what degree can we now, on the basis of extant knowledge, establish how the key determinants interact cumulatively in influencing the indicator?

The most influential cumulative effects on Indicator 5.1.2 arise from the interaction of the feasibility of trading in local markets for secondary manufacturing products, Canada's ability to compete in foreign markets, and trade dynamics and barriers with the United States (Stennes et al., 2005; DeLong et al., 2007). These interactions are far more influential than the availability of wood fibre and primary manufacturing products (DeLong et al., 2007). These cumulative effects are further influenced by policies to promote or regulate local secondary manufacturing in the various jurisdictions.

3.4. Is the indicator largely unrelated to any other, as described by the linkages assessment and evaluation of key determinants? If so, and the indicator was defined as uninfluenced by climate change in the independent assessment, then it can be placed in category one.

Indicator 5.1.2 is not overly related to other indicators within the C&I framework. However, it has important connotations for employment and the well-being of forest dependent communities. We do not recommend assigning it to category one.

- 3.5. Do the indirect effects of climate change via the linkages with other indicators influence the indicator's ability to signal SFM, regardless of which category was assigned in the independent climate-change assessment?

The influence of climate change on Indicator 5.1.2 is only via interaction with other indicators and determinants. Under the assumption that climate change will have no direct influence on the global demand for secondary manufacturing timber products, we can concur that the chief influence of climate change on this Indicator will be through climate-driven increases in the global supply of wood fibre and regional shortages in some parts of Canada (Perez-Garcia et al., 2002; Browne & Hunt, 2007). These can all cause fluctuations in the supply of primary solid wood products for secondary manufacturing.

- 3.6. If the indicator's ability to signal SFM progress remains the same under a changing climate, can we conclude no negative influence and leave it unchanged? These indicators can be placed in category two.

The ability of Indicator 5.1.2 to signal SFM progress will not be diminished to the point that modification of the indicator is necessary. We therefore recommend assigning it to category two, *Unmodified Indicators*.

- 3.7. If the indicator's ability to signal SFM progress deteriorates when one assumes a changing climate, then what modifications are possible or warranted to improve its ability sufficiently for it to remain among the C&I-SFM? These indicators can be placed in category three.

Not applicable. We do not recommend modifying Indicator 5.1.2.

- 3.8. If no modifications seem possible or warranted, are we ready to recommend abandonment of the indicator? These indicators can be placed in category four.

Not applicable.

- 3.9. If we recommend abandonment, can we identify any new and closely allied indicators that might suit our needs better under climate change? Are there any other reasons for the creation of an additional indicator? These indicators can be placed in category five.

Not applicable.

- 3.10. Have extant climate-change impacts made this indicator more pertinent to SFM (i.e. 2.3 and the mountain pine beetle)? These indicators can be placed in category five or considered for conversion from a supporting to a core indicator (where applicable).

There are no discernable or highly pertinent effects of climate change on the value of secondary manufacturing of timber products, or the proportion of harvested volume used in this value-added production.

3.11. How should the surviving indicator (the original, modified, or new) be modelled and monitored so that stronger SFM signals may be generated?

As with the majority of economic state indicators, data are compiled by the Canadian Forest Service and retrieved from Statistics Canada (CCFM, 2006). This approach to the measurement of Indicator 5.1.2 and its feasibility will not be affected by climate change in any foreseeable manner, and need not be modified in future assessments.

3.12. Does this indicator track an entity whose relationship with climate is regionally variable?

Differences in the value of secondary manufacturing of timber products per volume harvested is incredibly variable between jurisdictions, as approximately 87% of the value added by secondary manufacturing is generated in Ontario, Quebec, and British Columbia, and around half of that is generated in Ontario alone (CCFM, 2006). This will likely far outweigh the regional influence of climate change on the supply of wood fibre.

INDICATOR 5.1.3 PRODUCTION, CONSUMPTION, IMPORTS AND EXPORTS OF TIMBER PRODUCTS

1. Linkages Assessment

Table 1.1. Indicators influencing Indicator 5.1.3.

Indicator 5.1.3	Influencing Indicators
First order positive	5.3.1
First order negative	None
First order bi-directional	None

Table 1.2. Indicators influenced by Indicator 5.1.3.

Indicator 5.1.3	Influenced Indicators
First order positive	4.1.4, 5.1.1, 5.1.2, 5.3.1, 5.3.3, 5.3.4, 5.3.5, and 6.3.3
First order negative	None
First order bi-directional	4.1.3 and 5.2.2

- 1.1. Which indicators are influencing and influenced directly (first-order interactions) by the indicator in question? Is the indicator more of a driver of change in other indicators, or being driven by other indicators?

Indicator 5.1.3 is primarily linked to other indicators within Criterion 5, with the exception of Indicators 4.1.3, 4.1.4, and 6.3.3. It is only directly influenced by one other indicator, 5.3.1, and influences 10 other indicators. Indicator 5.1.3 is a major driver of many of the socioeconomic aspects of the forest sector, though is not influenced by many other indicators within the C&I framework.

- 1.2. List the indicators described as ‘relevant indicators under other criteria’ in the 2003 C&I-SFM. Is there any conflict with the interactions described in the matrix?

The economic welfare of the forest sector is largely dependent on the production, consumption, imports, and exports of timber products that are tracked by Indicator 5.1.3, but is also highly connected to the condition, productivity, and diversity of forest ecosystems (i.e. Criteria 1 and 2). Indicators within Element 5.1 are described as dependent on the area, type, age, and growing stock of forests, as monitored by Indicators 1.1.1, 1.1.2, and 2.1. However, these relationships would only be reflected by second-order interactions within the interaction matrix.

- 1.3. Are there any overlaps or gaps in the relationship with indicators defined in Eddington and colleague’s (2009) report?

The FFEI project is focused on monitoring key species and ecological processes in order to signal and anticipate the response of forest and rangeland to climate change. There is no inclusion of the socio-economic dimension of SFM, so there is no overlap between the C&I framework and the Eddington et al. (2009) report.

2. Independent Climate-Change Assessment

- 2.1. Provide in detail, a qualitative description of what are the expected direct effects of climate change on the indicator, using a broad representation from the literature.**

Many studies have found that climate change will likely influence the production, consumption and international trade of timber products (Perez-Garcia et al., 2002; Kirilenko & Sedjo, 2007; Williamson et al., 2008; Jonsson, 2009). In these studies, the effects on global markets are driven primarily by changes in forest productivity around the globe and the corresponding harvest response. Naturally, as with all systems response to global environmental change, these predictions are highly uncertain and variable, and largely dependent on the assumptions of future emissions scenarios (Perez-Garcia et al., 2002). Furthermore, many of these studies employ coarse-resolution global models for simulating changes in the net primary productivity of forests in response to climatic change, which do not incorporate many integral determinants of forest ecosystems, such as natural disturbance regimes, the political environment of different nations, and many other complex socioeconomic factors of regional and national economies. All or any of these determinants may lead to a decline in the economic welfare of the forest sector in different regions under climate change (Browne & Hunt, 2007).

A significant finding of many of these studies is that the global increase in timber supply causes a decline in prices, which subsequently leads to an overall increase in consumption of forest products and economic welfare of the global forest sector (Sohngen & Mendelsohn, 1998; Irland et al., 2001; Perez-Garcia et al., 2002). Moreover, it is predicted that regardless of the changing climate, the global demand for forest products will increase as a result of population and economic growth in major developing countries like China and India (Lee & Lyon, 2004).

The situation will of course be highly variable between different countries. In a Canadian context, Perez-Garcia and colleagues (2002) predict that despite the likely positive gains in timber supply due to climate change, the declining prices of timber products will lead to a decrease in total harvest rates in order to minimize economic losses to the forest sector. In relative terms, Canada has a high cost of production for timber products, which is also predicted to negatively influence forest-sector economic welfare (Perez-Garcia et al., 2002). The implications of climate change for the forest sector will likely be negative for many specific regions and forest-dependent communities because of these economic impacts, but also because of the ecological consequences of more frequent and severe natural disturbances (Browne & Hunt, 2007; Williamson et al., 2008).

- 2.2. Given expected changes in Canada's climate, describe if and how the indicator's ability to signal progress towards SFM remains unchanged.

The SFM signal that is generated by Indicator 5.1.3 will be affected by climate change.

- 2.3. If an indicator's ability to signal progress towards SFM will be changed, describe if and how the indicator may become worse or better at signalling SFM progress.

The Canadian forest sector is highly dependent on foreign markets, whose fluctuating nature already provides challenges to the predictability and responsiveness of Indicator 5.1.3. The myriad of complex economic and social factors affecting Indicator 5.1.3 run the gamut from the price of fuel to consumer preferences. These relationships are now further obscured by the influence of climate change on quality, quantity, and type of wood available, and subsequently the production, consumption, and trade of timber products.

The goal of Indicator 5.1.3 is to illuminate the benefits to the Canadian economy from the production, consumption, and trade of timber products. The degree to which we can predict future fluctuations in Indicator 5.1.3 and how they respond to management actions in a changing climate will be severely reduced.

3. Integrated Climate-Change Assessment

- 3.1. What are the key determinants of the indicator (i.e. what causes it to change when it does change);

- a) Among other indicators in the C&I framework?
 - **There is only one key determinant of Indicator 5.1.3 within the C&I framework, yet it is very important relationship. The annual harvest of timber and its sustainability (Indicator 5.3.1) is a major driver of Indicator 5.1.3 and the economic benefits from SFM.**
- b) Among determinants not within the C&I framework?
 - **Global and domestic markets and demand for timber products are a major determinant of Indicator 5.1.3. Specifically, because Canada exports an estimated 79% of finished forest products as of the 2005 C&I-SFM assessment (CCFM, 2006), foreign markets are critical determinants of Indicator 5.1.3, as was evident during the crash of the United States housing market in 2006.**

- 3.2. For what other entities is this indicator a key determinant (i.e. when it changes, what other indicators are influenced to change);

a) Among other indicators in the C&I framework?

- **Indicator 5.1.3 is a major determinant of the economic benefits derived from timber products, and as such is influential on other indicators within Element 5.1, such as Indicators 5.1.1 and 5.1.2.**
- **Indicator 5.1.3 also reflects the demand for timber products and is therefore a determinant of the annual timber harvest (Indicator 5.3.1).**
- **Indicator 5.1.3 is influential on employment within the forest sector, as represented by Indicator 5.3.5 and 6.3.3.**
- **Carbon cycling within the forest sector is also in part determined by Indicator 5.1.3, specifically the carbon that is stored in forest products and forest sector carbon emission (Indicators 4.1.3 and 4.1.4).**

b) Among determinants not within the C&I framework?

- **The forest sector is of course a partial determinant of the total Canadian economy and its welfare, and is linked with many other facets of society and the economy that are external to the C&I framework.**

3.3. To what degree can we now, on the basis of extant knowledge, establish how the key determinants interact cumulatively in influencing the indicator?

To understand to cumulative influence of the different determinants of the production, consumption, imports, and exports of timber products it is useful to separate the socioeconomic determinants from the biophysical ones. It is conceptually simple to understand that Indicator 5.1.3 is very dependent on the quality, quantity, and type of wood fibre available from forest ecosystems. Climate change is predicted to increase this availability in many regions, yet we cannot expect a linear response of production, consumption, and trade of timber products. This is because of the cumulative influences of global market strength, trade dynamics, Canada's competitiveness in these markets, and future environmental and climate change policies and regulations.

3.4. Is the indicator largely unrelated to any other, as described by the linkages assessment and evaluation of key determinants? If so, and the indicator was defined as uninfluenced by climate change in the independent assessment, then it can be placed in category one.

Indicator 5.1.3, while not directly related to many indicators within the C&I framework, is highly dependent on many other factors within the global forest sector, and is also an

important determinant of the economic benefits derived from forests. We do not recommend assigning it to category one, *Uninfluenced Indicators*.

- 3.5. Do the indirect effects of climate change via the linkages with other indicators influence the indicator's ability to signal SFM, regardless of which category was assigned in the independent climate-change assessment?

Changes to the ability of Indicator 5.1.3 to signal SFM progress are entirely attributable to the indirect influence of climate change, primarily the response of both Canada's forest sector and global forest product markets to changes in the supply of wood fibre.

- 3.6. If the indicator's ability to signal SFM progress remains the same under a changing climate, can we conclude no negative influence and leave it unchanged? These indicators can be placed in category two.

Indicator 5.1.3 will likely suffer a reduction in the strength of the SFM signal it generates.

- 3.7. If the indicator's ability to signal SFM progress deteriorates when one assumes a changing climate, then what modifications are possible or warranted to improve its ability sufficiently for it to remain among the C&I-SFM? These indicators can be placed in category three.

The ability of Indicator 5.1.3 to signal our progress towards SFM will be diminished by a loss in the predictability, relevance, and responsiveness of the Indicator. However, we see no possible modifications to the Indicator that could either incorporate or minimize this uncertainty that is introduced by climate change. Consequently, we will assign Indicator 5.1.3 to category two, *Unmodified Indicators*.

- 3.8. If no modifications seem possible or warranted, are we ready to recommend abandonment of the indicator? These indicators can be placed in category four.

We are not ready to recommend the abandonment of Indicator 5.1.3, despite the reduction in its effectiveness. Canada is the world's biggest exporter of forest products (CCFM, 2006), so monitoring international trade is critical to SFM. Furthermore, Indicator 5.1.3 was found to be highly influential on other indicators within Criterion 5 in the linkages assessment. It is likely that we will have to simply rely on the weakened SFM signal generated by Indicator 5.1.3.

- 3.9. If we recommend abandonment, can we identify any new and closely allied indicators that might suit our needs better under climate change? Are there any other reasons for the creation of an additional indicator? These indicators can be placed in category five.

Not applicable. There are no additional indicators that we recommend in place of or related to Indicator 5.1.3.

- 3.10. Have extant climate-change impacts made this indicator more pertinent to SFM (i.e. 2.3 and the mountain pine beetle)? These indicators can be placed in category five or considered for conversion from a supporting to a core indicator (where applicable).

These anticipated global-market dynamics under climate change are predicted using integrated, forecast-modelling techniques that rely on future assumptions about climate change. However, the current losses in timber resources and previously described increase in allowable annual cut in British Columbia in response to the mountain pine beetle (*Dendroctonus ponderosae*) epidemic could be seen as pertinent to Indicator 5.1.3 (Pederson, 2004; Spittlehouse, 2005).

- 3.11. How should the surviving indicator (the original, modified, or new) be modelled and monitored so that stronger SFM signals may be generated?

The measurability of Indicator 5.1.3 will be unaffected by climate change. The economic data collected on the production, consumption, exports, and imports of softwood lumber, wood pulp, and newsprint by Statistics Canada will more than likely remain an adequate data source for future monitoring.

- 3.12. Does this indicator track an entity whose relationship with climate is regionally variable?

The production and export of timber products will likely vary to a significant degree because of regional climate-change impacts.

INDICATOR 5.1.4 CONTRIBUTION OF NON-TIMBER FOREST PRODUCTS AND FOREST-BASED SERVICES TO THE GROSS DOMESTIC PRODUCT

1. Linkages Assessment

Table 1.1. Indicators influencing Indicator 5.1.4.

Indicator 5.1.4	Influencing Indicators
First order positive	5.1.5 and 5.3.2
First order negative	None
First order bi-directional	1.1.2

Table 1.2. Indicators influenced by Indicator 5.1.4.

Indicator 5.1.4	Influenced Indicators
First order positive	5.3.3
First order negative	None
First order bi-directional	None

- 1.1. Which indicators are influencing and influenced directly (first-order interactions) by the indicator in question? Is the indicator more of a driver of change in other indicators, or being driven by other indicators?

Indicator 5.1.4 is directly influenced by only three other indicators, including the biophysical Indicator 1.1.2. It influences only one other Indicator directly. Indicator 5.1.4 is a context indicator, and thus is not a major driver of change in other indicators.

- 1.2. List the indicators described as ‘relevant indicators under other criteria’ in the 2003 C&I-SFM. Is there any conflict with the interactions described in the matrix?

Criteria 1 and 2 are described as highly relevant to the economic benefits from forests and SFM to society. These benefits depend on the area, type, age, and growing stock of forests, as tracked by Indicators 1.1.1, 1.1.2, and 2.1. These relationships would be reflected as second-order interactions via Indicator 5.3.2 within the interaction matrix.

- 1.3. Are there any overlaps or gaps in the relationship with indicators defined in Eddington and colleague’s (2009) report?

The FFEI project is focused on monitoring key species and ecological processes in order to signal and anticipate the response of forest and rangeland to climate change. There is no inclusion of the socio-economic dimension of SFM, so there is no overlap between the C&I framework and the Eddington et al. (2009) report.

2. Independent Climate-Change Assessment

- 2.1. Provide in detail, a qualitative description of what are the expected direct effects of climate change on the indicator, using a broad representation from the literature.

Non-timber forest products (NTFP) and forest-based services are incredibly diverse, ranging from more tangible products like wild edible berries, mushrooms, and maple products to complex and labour-intensive biotechnologies to the less-tangible recreational services and carbon credits (Duchesne & Wetzel, 2002; CCFM, 2006). It is particularly difficult to assign monetary value to many of the NTFP and forest-based services that forest ecosystems provide (Anderson et al., 2010). One prominent example of this difficulty is the role that forests and wetlands play in maintaining water quality, which is one of the most critical forest-based services for society that is dramatically undervalued.

All NTFP and forest-based services are in some way linked to the health of a forest and its biological diversity (Hauer et al., 2001; Johnston et al., 2010). For this reason, they will be vulnerable to climate change because ecosystem, species, and genetic diversity are all threatened (Gray, 2005), and we can anticipate a decline in their contribution to the gross domestic product (GDP). However, there will be some NTFP and forest-based services that may gain in relevance and in their contribution to GDP under climate change. Several studies predict that there will be an increase in forest-based tourism because of warmer and longer summers (Scott, 2003; Browne & Hunt, 2007). Forest carbon offsets and credits owe their creation to climate change policies and international agreements to reduce carbon emissions (IPCC, 2007; Johnston et al., 2010). Moreover, biofuels, biochemicals, biomaterials, and nanotechnology are all environmental products derived from the forest (CCFM, 2005, NRCan, 2011). While there is some debate over how to label these products (timber versus non-timber forest products), it is clear that the growing demand for these needs to be captured in SFM monitoring.

- 2.2. Given expected changes in Canada's climate, describe if and how the indicator's ability to signal progress towards SFM remains unchanged.

An existing issue with Indicator 5.1.4 is that it is exceedingly difficult and often inappropriate to measure the total economic value of NTFP and forest-based services, which jeopardizes both the measurability and feasibility of their contribution to the GDP. Detrimental effects from climate change on biological diversity and the expansion of the new forest subsectors have major implications for NTFP and forest-based services, as well as their relevance to SFM. However, we feel these are far more pertinent to Indicators 5.1.5 and 5.3.2. We conclude that despite the difficulty in measuring Indicator 5.1.4, it will not be further diminished in its ability to signal SFM progress, due largely the relatively high understandability and responsiveness of the Indicator.

- 2.3. If an indicator's ability to signal progress towards SFM will be changed, describe if and how the indicator may become worse or better at signalling SFM progress.

Indicator 5.1.4 will not be significantly diminished in its ability to signal our progress towards SFM. However, the growing relevance of biotechnologies and bioproducts derived from the forest will necessitate some modification to how the Indicator is measured.

3. Integrated Climate-Change Assessment

3.1. What are the key determinants of the indicator (i.e. what causes it to change when it does change);

- a) Among other indicators in the C&I framework?
 - **The key determinant of the contribution of NTFP and forest-based services to the GDP is Indicator 5.1.5, which tracks their economic value.**
 - **Forest-based services like tourism and guiding/outfitting, while significant across the country, have a strong association with protected areas, making Indicator 1.1.2 a determinant of Indicator 5.1.4.**
 - **Biological diversity (Criterion 1) forms the basis for the majority of NTFP and forest-based services, and as such is a determinant of Indicator 5.1.4, though not directly represented in the interaction matrix.**

- b) Among determinants not within the C&I framework?
 - **The growing recognition of NTFP industries as a viable economic sector and the subsequent growing contribution of many NTFP to the GDP, such as maple products (CCFM, 2006), illustrate the role of domestic and international demand, trade patterns, and market dynamics as key determinants of Indicator 5.1.4.**
 - **A final determinant of Indicator 5.1.4 is the contribution of other economic sectors to the GDP of Canada in relation to NTFP and forest-based services.**

3.2. For what other entities is this indicator a key determinant (i.e. when it changes, what other indicators are influenced to change);

- a) Among other indicators in the C&I framework?
 - **Indicator 5.1.4 has some influence over the return on capital employed and Indicator 5.3.3.**

- b) Among determinants not within the C&I framework?

- **The contribution NTFP and forest-based services to the GDP are significantly smaller than other sectors of the economy, including timber product industries. Regardless, it is still a determinant of the GDP and of Canadian economic welfare, especially in many forest-based communities.**

3.3. To what degree can we now, on the basis of extant knowledge, establish how the key determinants interact cumulatively in influencing the indicator?

The total contribution of NTFP and forest-based services to the GDP is simply a sum of the value of all the combined subsectors that are measured. However, some of these different NTFP and forest-based services, and their associated management activities, may interact cumulatively to influence Indicator 5.1.4. For example, severe habitat modification on Christmas tree farms will adversely affect local populations of fur-bearing mammals and the availability of wild edibles that depend on intact, mature forests. Moreover, the cumulative economic effects on these subsectors arising from variable consumer demand, international trade patterns, market stability, and tourism emphasise the complex dynamics of the interacting determinants of Indicator 5.1.4.

3.4. Is the indicator largely unrelated to any other, as described by the linkages assessment and evaluation of key determinants? If so, and the indicator was defined as uninfluenced by climate change in the independent assessment, then it can be placed in category one.

Indicator 5.1.4 is largely unrelated to other indicators within the C&I framework. However, climate change may influence the GDP contributions of different NTFP and forest-based services, so Indicator 5.1.4 should not be assigned to category one.

3.5. Do the indirect effects of climate change via the linkages with other indicators influence the indicator's ability to signal SFM, regardless of which category was assigned in the independent climate-change assessment?

The influence of climate change on forest ecosystems and biological diversity has implications for the supply of NTFP and their sustainable harvest, as tracked by Indicator 5.3.2. This linkage with Indicator 5.3.2 is the vehicle for climate-change interaction with Indicator 5.1.4 that could vary the contribution of NTFP and forest-based services to the GDP.

3.6. If the indicator's ability to signal SFM progress remains the same under a changing climate, can we conclude no negative influence and leave it unchanged? These indicators can be placed in category two.

The ability of Indicator 5.1.4 to signal SFM is not overly diminished by climate change, but the indicator does increase in relevance, and should not be assigned to category two.

- 3.7. If the indicator's ability to signal SFM progress deteriorates when one assumes a changing climate, then what modifications are possible or warranted to improve its ability sufficiently for it to remain among the C&I-SFM? These indicators can be placed in category three.

Like the situation with Indicator 5.1.1, the inclusion of a new subsector's contribution to the GDP was necessary because of its growing relevance under climate change. We recommend that Indicator 5.1.1 be modified to include the contribution of carbon credits, biotechnologies, and bioproducts to the GDP.

- 3.8. If no modifications seem possible or warranted, are we ready to recommend abandonment of the indicator? These indicators can be placed in category four.

Not applicable.

- 3.9. If we recommend abandonment, can we identify any new and closely allied indicators that might suit our needs better under climate change? Are there any other reasons for the creation of an additional indicator? These indicators can be placed in category five.

Not applicable.

- 3.10. Have extant climate-change impacts made this indicator more pertinent to SFM (i.e. 2.3 and the mountain pine beetle)? These indicators can be placed in category five or considered for conversion from a supporting to a core indicator (where applicable).

One pertinent example to the relevance of Indicator 5.1.4 is that of the emerging marketplace for carbon credits. Maximizing the sequestration and storage of carbon in the living and dead biomass of forest ecosystems is a widely recognized strategy to mitigate climate change (UNFCCC, 1997; Freedman et al., 2009). International agreements like the Kyoto Protocol recognize the validity of land use, land-use change, and forestry activities to offset carbon emissions, and have lead to the creation initiatives for the trading and sale of carbon credits, such as Canada's offset System for Greenhouse Gases (Environment Canada, 2008).

- 3.11. How should the surviving indicator (the original, modified, or new) be modelled and monitored so that stronger SFM signals may be generated?

Data on the contributions of various sectors of the Canadian economy to the GDP are prominent economic statistics that are collected by Statistics Canada. However, data on the contribution of many NTFP and forest-based services are unavailable and often quite challenging to value (CCFM, 2006; Anderson et al., 2010). As such, the CCFM 2005 C&I-SFM assessment drew from a wider variety of data sources and estimates for Indicator 5.1.4 than was required for Indicator 5.1.1, such as Agriculture and Agri-Food Canada and provincial/territorial-scale initiatives in several of Canada's jurisdictions. It will also be important to account for carbon credits traded in burgeoning carbon markets.

3.12. Does this indicator track an entity whose relationship with climate is regionally variable?

Indicator 5.1.4 measures contributions to the GDP, without addressing jurisdictional or regional differences in contributions, so the influence of climate change on Indicator 5.1.4 will not be spatially sensitive.

INDICATOR 5.1.5 VALUE OF UNMARKETED NON-TIMBER FOREST PRODUCTS AND FOREST-BASED SERVICES

1. Linkages Assessment

Table 1.1. Indicators influencing Indicator 5.1.5.

Indicator 5.1.5	Influencing Indicators
First order positive	6.5.3
First order negative	5.3.2
First order bi-directional	1.1.2

Table 1.2. Indicators influenced by Indicator 5.1.5.

Indicator 5.1.5	Influenced Indicators
First order positive	5.1.4
First order negative	None
First order bi-directional	None

- 1.1. Which indicators are influencing and influenced directly (first-order interactions) by the indicator in question? Is the indicator more of a driver of change in other indicators, or being driven by other indicators?

Indicator 5.1.5 is directly influenced by three other indicators. It influences just one other indicators, Indicator 5.1.4, and is thus largely unrelated to other indicators the C&I framework. Indicator 5.1.5 is not a significant driver of change in other indicators and vice versa.

- 1.2. List the indicators described as ‘relevant indicators under other criteria’ in the 2003 C&I-SFM. Is there any conflict with the interactions described in the matrix?

The total value of non-timber forest products (NTFP) and forest-based services is significantly linked to the condition, productivity, and diversity of forest ecosystems, as represented by Criteria 1 and 2, and especially Indicators 1.1.1, 1.1.2, and 2.1. These relevant relationships described in the 2003 C&I-SFM report would be reflected as second-order interactions in the interaction matrix, with the exception of the relevance of Indicator 1.1.2 to many forest-based services.

- 1.3. Are there any overlaps or gaps in the relationship with indicators defined in Eddington and colleague’s (2009) report?

The FFEI project is focused on monitoring key species and ecological processes in order to signal and anticipate the response of forest and rangeland to climate change. There is no inclusion of the socio-economic dimension of SFM, so there is no overlap between the C&I framework and the Eddington et al. (2009) report.

2. Independent Climate-Change Assessment

- 2.1. Provide in detail, a qualitative description of what are the expected direct effects of climate change on the indicator, using a broad representation from the literature.

The goal of Indicator 5.1.5 is to provide some measure of the economic benefits derived from unmarketed forest-ecosystem goods and services. However, it is exceedingly difficult measure and assign value to non-commodity, forest-based services such as recreation and aesthetics, the maintenance of water quality, and wildlife habitat (Anderson et al., 2010). These services are not traditionally traded in a market-place and therefore not assigned value, which can lead to major disincentives for forest managers to incorporate these forest-based services into their planning (Solano-Rivera, 2010). Anderson and colleagues (2010) provide an in-depth review of the state of knowledge on the valuation of ecosystem services. While we will not cover this already challenging issue to any depth here, we anticipated that sufficiently accounting for the value of untraded NTFP and forest-based services, financially and otherwise, will be made all the more difficult by climate change.

In previous C&I-SFM assessments, the focus of Indicator 5.1.5 has been on the recreational values and services of Canada's forests, measured by survey in 2000 and case study in 2005 (CCFM, 2000; CCFM, 2006). We can expect physical and ecological impacts of climate change on forest areas with high recreational value (Scott & Lemieux, 2005; Johnston et al., 2010). These include the increase in frequent and severe natural disturbances and changes in forest structure and composition, which invalidate the assumptions of biogeographic stability that afflict protected areas planning in Canada (Scott & Lemieux, 2005; Williamson et al., 2009). Conversely, there is potential for climate change to cause increases in nature-based tourism due to longer, warmer summers (Scott, 2003).

- 2.2. Given expected changes in Canada's climate, describe if and how the indicator's ability to signal progress towards SFM remains unchanged.

The ability of Indicator 5.1.5 to signal our progress towards SFM will be diminished by climate change.

- 2.3. If an indicator's ability to signal progress towards SFM will be changed, describe if and how the indicator may become worse or better at signalling SFM progress.

Indicator 5.1.5 is an economic condition/response indicator, and as with the majority of these indicators in the C&I framework, it will suffer a decline in its predictability due to climate change. We can also expect a decline in responsiveness and relevance due to the previously described impacts of climate change on protected areas if the current approach to monitoring is held. This Indicator has existing challenges in its measurability and feasibility. However, its anticipated performance under climate change, without considering these existing deficiencies, does not necessarily warrant any further action.

3. Integrated Climate-Change Assessment

3.1. What are the key determinants of the indicator (i.e. what causes it to change when it does change);

a) Among other indicators in the C&I framework?

- **The annual harvest of NTFP and Indicator 5.3.2 could be seen as a determinant of Indicator 5.1.5. However, Indicator 5.1.5 is more focused on the value of forest-based services than NTFP in recent monitoring initiatives.**
- **The assessment of Indicator 5.1.5 in the 2005 C&I-SFM 2005 status report focused primarily on the non-market benefits derived from protected areas in Ontario, and as such, Indicator 1.1.2 is a significant determinant.**
- **Investment in timber products industry research and development (Indicator 6.5.3) is a determinant of Indicator 5.1.5.**

b) Among determinants not within the C&I framework?

- **The value of NTFP and forest-based services like recreation and tourism is highly dependent on subjective attributes, like the aesthetics and natural beauty of forest landscapes.**
- **Many other socioeconomic factors influence Indicator 5.1.5 that are external to the C&I framework. These could range from the proximity of natural areas to major urban cores, to the marketing of different recreational areas or tourism organizations.**

3.2. For what other entities is this indicator a key determinant (i.e. when it changes, what other indicators are influenced to change);

a) Among other indicators in the C&I framework?

- **Indicator 5.1.5 is tightly linked with the contribution of marketed NTFP to the GDP, and therefore determines Indicator 5.1.4.**

b) Among determinants not within the C&I framework?

- **The importance of many NTFP and forest-based services to the rural and Aboriginal population of Canada and traditional lifestyles is largely external to the C&I framework.**

- 3.3. To what degree can we now, on the basis of extant knowledge, establish how the key determinants interact cumulatively in influencing the indicator?

It is challenging to discern the interaction of the determinants of Indicator 5.1.5, and the cumulative effects arising from these interactions, just as it is challenging to measure the value unmarketed NTFP and forest-based services. Keeping consistent with the focus on recreational services of forest ecosystems, it is likely that the cumulative and somewhat subjective influence different forest ecosystems, wetlands, waterbodies, and enduring geomorphological features on the aesthetic and recreational value of an area and the accessibility of these areas are the most important interactions for Indicator 5.1.5.

- 3.4. Is the indicator largely unrelated to any other, as described by the linkages assessment and evaluation of key determinants? If so, and the indicator was defined as uninfluenced by climate change in the independent assessment, then it can be placed in category one.

Indicator 5.1.5 is largely unrelated to other indicators within the C&I framework, as defined by the direct linkages in the interaction matrix. However, given the aforementioned influence of climate change on the Indicator, we do not recommend assigning it to category one.

- 3.5. Do the indirect effects of climate change via the linkages with other indicators influence the indicator's ability to signal SFM, regardless of which category was assigned in the independent climate-change assessment?

Indicator 5.1.5 has relatively few direct linkages with other indicators in the C&I framework. Because it tracks the value of unmarketed NTFP and forest-based services, it is less influenced by economic climate-change impacts that are pertinent to other indicators within Element 5.1. It is however influenced by the impacts on several other biophysical indicators, namely those on Indicators 1.1.1, 1.1.2, and 2.3. Indicator 5.1.5 also has important connotations for employment and the well-being of forest-dependent communities and First Nations.

- 3.6. If the indicator's ability to signal SFM progress remains the same under a changing climate, can we conclude no negative influence and leave it unchanged? These indicators can be placed in category two.

The ability of Indicator 5.1.5 to signal SFM progress in a changing climate will be somewhat reduced. However, there are no obvious modifications that could be done to mitigate this reduction and the Indicator will still maintain most of its function under climate change. We therefore recommend assigning it to category two, *Unmodified Indicators*.

- 3.7. If the indicator's ability to signal SFM progress deteriorates when one assumes a changing climate, then what modifications are possible or warranted to improve its ability sufficiently for it to remain among the C&I-SFM? These indicators can be placed in category three.

Not applicable.

- 3.8. If no modifications seem possible or warranted, are we ready to recommend abandonment of the indicator? These indicators can be placed in category four.

Not applicable.

- 3.9. If we recommend abandonment, can we identify any new and closely allied indicators that might suit our needs better under climate change? Are there any other reasons for the creation of an additional indicator? These indicators can be placed in category five.

Not applicable.

- 3.10. Have extant climate-change impacts made this indicator more pertinent to SFM (i.e. 2.3 and the mountain pine beetle)? These indicators can be placed in category five or considered for conversion from a supporting to a core indicator (where applicable).

Most of the severe impacts of climate change on forests that have been observed in recent years are pertinent to the services produced by the affected ecosystems (Johnston et al., 2010). Some more specific extent examples to the recreational uses of forests are the same as those described as pertinent to Indicator 1.1.2. For example, in Banff and Kootenay national parks the mountain pine beetle (*Dendroctonus ponderosae*) outbreak has caused widespread mortality in the parks' forests and is seen in a highly negative light by the public (McFarlane et al., 2006). In the United States' Yellowstone National Park, drought conditions and a subsequent severe forest-fire season in 1998 severely affected forest conditions in the Park, and lead to an estimated \$60,000,000 USD loss in tourism revenue (Franke, 2000; Scott et al., 2007).

- 3.11. How should the surviving indicator (the original, modified, or new) be modelled and monitored so that stronger SFM signals may be generated?

There are no recommended changes to the approach to monitoring Indicator 5.1.5.

3.12. Does this indicator track an entity whose relationship with climate is regionally variable?

The influence of climate change on the value of NTFP and forest-based services, particularly on recreational values, will be regionally variable.

INDICATOR 5.2.1 *FOREST AREA BY TIMBER TENURE*

1. Linkages Assessment

Table 1.1. Indicators influencing Indicator 5.2.1.

Indicator 5.2.1	Influencing Indicators
First order positive	None
First order negative	None
First order bi-directional	1.1.1

Table 1.2. Indicators influenced by Indicator 5.2.1.

Indicator 5.2.1	Influenced Indicators
First order positive	None
First order negative	None
First order bi-directional	2.3, 2.5, 5.2.2, 5.3.1, 5.3.5, and 6.3.3

- 1.1. Which indicators are influencing and influenced directly (first-order interactions) by the indicator in question? Is the indicator more of a driver of change in other indicators, or being driven by other indicators?

Indicator 5.2.1 is only influenced by one other indicator, Indicator 1.1.1. It influences six other indicators directly, from Criteria 2, 5, and 6. Indicator 5.2.1 is more of a driver of change in other indicators than it is driven to change by them.

- 1.2. List the indicators described as ‘relevant indicators under other criteria’ in the 2003 C&I-SFM. Is there any conflict with the interactions described in the matrix?

There are many indicators that are listed as relevant to the social and economic benefits of SFM, ranging from type and condition of forests, tracked by Indicators 1.1.1 and 2.1, to the social costs of instability in forest-based communities, tracked by indicators in Element 6.3. However, there are no indicators ascribed explicitly to the distribution of benefits from the forest sector. Conversely, the incidence of tenure arrangements that allow some community control is described as relevant to the well-being of forest-based communities.

- 1.3. Are there any overlaps or gaps in the relationship with indicators defined in Eddington and colleague’s (2009) report?

The FFEI project is focused on monitoring key species and ecological processes in order to signal and anticipate the response of forest and rangeland to climate change. There is no inclusion of the socio-economic dimension of SFM, so there is no overlap between the C&I framework and the Eddington et al. (2009) report.

2. Independent Climate-Change Assessment

- 2.1. Provide in detail, a qualitative description of what are the expected direct effects of climate change on the indicator, using a broad representation from the literature.

Canada's Crown forest tenures are a potential tool to influence the behaviour of licensees on public forest land (Haley & Nelson, 2007). Given that 93% of Canada's forested land is either provincial or federal Crown land (CCFM, 2006), tenure systems have the potential to be a major tool in climate-change adaptation and mitigation. However, we are concerned with the impacts of climate change on Crown forest tenures, and our ability to monitor and assess timber tenures under global environmental change. Thus, we see no direct influence of climate change on Indicator 5.2.1.

The indirect effects of climate change may slightly diminish the ability of Indicator 5.2.1 to signal progress towards SFM. Forest timber tenure is a highly complex issue with a long list of stakeholders and divergent opinions on its role in SFM (Haley & Luckart, 1990; Haley & Nelson, 2007). There are arguments, chiefly from industrial license holders, that the regulatory 'command and control' approach of Crown forest tenures as opposed a more market-controlled paradigm has contributed to the fall of forestry in Canada in the past decade (Haley and Nelson, 2007). There are also movements towards and smaller, community-based tenure systems that will benefit forest community well-being and resilience (Beckley, 1998).

The influence of climate change on key components of forest ecosystems, tracked by Indicators in Criteria 1 and 2, may further the current shifts in values around public forests that could in turn influence Crown forest tenure agreements. License agreements on Crown land may therefore be a tool for policy implementation around climate-change adaptation. Conversely, Indicator 5.2.1 may be indirectly influenced by climate change due to physical changes in forest area. These changes include dieback of forests in warmer, moisture-limited regions and treeline migration in higher altitudes and latitudes (Williamson et al., 2009).

- 2.2. Given expected changes in Canada's climate, describe if and how the indicator's ability to signal progress towards SFM remains unchanged.

The ability of Indicator 5.2.1 to signal the distribution of benefits from SFM may be diminished by climate change.

- 2.3. If an indicator's ability to signal progress towards SFM will be changed, describe if and how the indicator may become worse or better at signalling SFM progress.

Indicator 5.2.1 will like experience a decline in its predictability due to the climate-driven changes in forest area. Moreover, the potential for Crown forest license agreements to influence forest practices on public land, and thus the opportunities to promote climate-

change adaptation in forest management, increases the relevance of Indicator 5.2.1 in signalling SFM progress.

3. Integrated Climate-Change Assessment

3.1. What are the key determinants of the indicator (i.e. what causes it to change when it does change);

- a) Among other indicators in the C&I framework?
- **The distribution and diversity of forest ecosystems in Canada, tracked by Indicator 1.1.1, is a determinant of Indicator 5.2.1.**

- b) Among determinants not within the C&I framework?
- **The major determinants of Indicator 5.2.1 that external to the C&I framework include demands from industry and market forces that will dictate the stipulations of forest tenure agreements. Moreover, because forest tenure area refers to public lands, societal influence of forest policy is also a key determinant.**

3.2. For what other entities is this indicator a key determinant (i.e. when it changes, what other indicators are influenced to change);

- a) Among other indicators in the C&I framework?
- **Indicator 5.2.1 will be a determinant for many aspects of SFM that are regulated by tenure agreements on Crown land. These include Indicators 2.5, 2.3, and 5.3.1.**
- **Forest tenure is also influential on the distribution of benefits from forestry activities, such as the employment tracked Indicators 5.3.5 and 6.3.3.**

- b) Among determinants not within the C&I framework?
- **Indicator 5.2.1 is also a significant determinant of industry practices on public land in Canada.**

3.3. To what degree can we now, on the basis of extant knowledge, establish how the key determinants interact cumulatively in influencing the indicator?

The cumulative pressure of societal and industry demands on practices on Crown forest land are a key driver of change in forest policy and regulation. Moreover, because forest

tenure is linked to the current political body in power, it is subject the cumulative interactions of the political cycles in Canada. We cannot fully assess the intricacies and cumulative interactions of the many complex determinants of Indicator 5.2.1.

- 3.4. Is the indicator largely unrelated to any other, as described by the linkages assessment and evaluation of key determinants? If so, and the indicator was defined as uninfluenced by climate change in the independent assessment, then it can be placed in category one.

Indicator 5.2.1 is related to several other indicators in the C&I framework that are predicted to be severely affected by climate change. It is influential on key biophysical indicators like 2.3 and 2.5, as Crown forest tenures are key determinants of the area of forest disturbed by timber harvest and subsequently reforested. As such, we recommend not placing this Indicator in category one.

- 3.5. Do the indirect effects of climate change via the linkages with other indicators influence the indicator's ability to signal SFM, regardless of which category was assigned in the independent climate-change assessment?

There is a strong potential for Indicator 5.2.1 to be indirectly influenced by climate change due to impacts of climate change on forest-ecosystem condition and productivity. The most significant of these relationships is that with Indicator 2.2, as climate change will likely cause changes in forest area in the climate extremes of Canada.

- 3.6. If the indicator's ability to signal SFM progress remains the same under a changing climate, can we conclude no negative influence and leave it unchanged? These indicators can be placed in category two.

The ability of Indicator 5.2.1 to signal SFM progress may be slightly diminished if it does not incorporate emergent societal demand for climate-change mitigation and adaptation on public land. However, this will be addressed by the new indicators recommend in the evaluations of Indicators 1.3.1 and 2.5, which address seed transfer guidelines and assisted migration initiatives.

- 3.7. If the indicator's ability to signal SFM progress deteriorates when one assumes a changing climate, then what modifications are possible or warranted to improve its ability sufficiently for it to remain among the C&I-SFM? These indicators can be placed in category three.

It may also be beneficial to modify Indicator 5.2.1 in response to its increasing relevance under climate change. We recommend adding an additional variable for measurement that would supplement the type and area of Aboriginal and non-Aboriginal timber tenures in Canada's jurisdictions that are currently monitored. The proportion of tenured area

with agreements that specifically address climate-change adaptations is an assessment variable that would greatly contribute to our ability to monitor the progress of climate-change integration into Canadian Crown forest policy

- 3.8. If no modifications seem possible or warranted, are we ready to recommend abandonment of the indicator? These indicators can be placed in category four.

Not applicable. We do not recommend abandoning this Indicator because it is an important measure of the distribution of benefits from forest management.

- 3.9. If we recommend abandonment, can we identify any new and closely allied indicators that might suit our needs better under climate change? These indicators can be placed in category five.

Not applicable.

- 3.10. Have extant climate-change impacts made this indicator more pertinent to SFM (i.e. 2.3 and the mountain pine beetle)? These indicators can be placed in category five or considered for conversion from a supporting to a core indicator (where applicable).

There are no current examples of tenure reform that have specifically addressed climate change in Canada that we could locate.

- 3.11. How should the surviving indicator (the original, modified, or new) be modelled and monitored so that stronger SFM signals may be generated?

There are no changes necessary to the most recent approach of measuring those variables already being monitored under Indicator 5.2.1. If the modification of Indicator 5.2.1 is accepted, then a similar measurement approach can be taken by assessing the total area of timber tenure with license agreements that acknowledge climate change in Canada's jurisdictions.

- 3.12. Does this indicator track an entity whose relationship with climate is regionally variable?

There is some regional variability in the influence of climate change on Indicator 5.2.1. Those forest regions that are more vulnerable to climate-induced changes in forest area may be under more immediate pressure to address climate change in Crown forest tenures.

INDICATOR 5.2.2 DISTRIBUTION OF FINANCIAL BENEFITS FROM THE TIMBER PRODUCTS INDUSTRY

1. Linkages Assessment

Table 1.1. Indicators influencing Indicator 5.2.2.

Indicator 5.2.2	Influencing Indicators
First order positive	None
First order negative	None
First order bi-directional	5.1.3, 5.2.1, 5.3.1, 5.3.2, 5.3.5, 5.3.6, and 6.3.3

Table 1.2. Indicators influenced by Indicator 5.2.2.

Indicator 5.2.2	Influenced Indicators
First order positive	None
First order negative	None
First order bi-directional	5.3.6 and 6.3.4

- 1.1. Which indicators are influencing and influenced directly (first-order interactions) by the indicator in question? Is the indicator more of a driver of change in other indicators, or being driven by other indicators?

Indicator 5.2.2 is influenced by seven other indicators, all from Criterion 5 except for Indicator 6.3.3. It only influences two other Indicators, 5.3.6 and 6.3.4. Indicator 5.2.2 is therefore more driven to change by other indicators than it is a driver of change.

- 1.2. List the indicators described as ‘relevant indicators under other criteria’ in the 2003 C&I-SFM. Is there any conflict with the interactions described in the matrix?

Several biophysical indicators are listed as relevant to the social and economic benefits from the forest sector, ranging from the type and extent of Canada’s forests and their condition, tracked by Indicators 1.1.1 and 2.1, to the well-being of forest-dependent communities, tracked by indicators in Element 6.3.3. However, there is no direct mention of other indicators that are relevant to the distribution of these benefits and Indicator 5.2.2.

- 1.3. Are there any overlaps or gaps in the relationship with indicators defined in Eddington and colleague’s (2009) report?

The FFEI project is focused on monitoring key species and ecological processes in order to signal and anticipate the response of forest and rangeland to climate change. There is no inclusion of the socio-economic dimension of SFM, so there is no overlap between the C&I framework and the Eddington et al. (2009) report.

2. Independent Climate-Change Assessment

- 2.1. Provide in detail, a qualitative description of what are the expected direct effects of climate change on the indicator, using a broad representation from the literature.

The distribution of financial benefits that are generated by the timber products sector is a vital measure of social and economic equity among the recipients. Indicator 5.2.2 tracks this distribution using the wages and salaries of industry workers, the profits of companies, and income going to government from stumpage fees, taxes, and public-enterprise profits (CCFM, 2006).

The core influence of climate change on almost all socioeconomic indicators are the impacts on forest-ecosystem condition and productivity and on biological diversity, and therefore on indicators in Criteria 1 and 2 (Williamson et al., 2009). of particular import to Indicator 5.2.2, and specifically to the distribution of wages and salaries, will be short-term impacts on timber supply and timber harvests due to more frequent and severe natural disturbances and the subsequent increasing demand for salvage harvests (Williamson et al., 2008; Johnston et al., 2010). The long-term implications of a global increase in the supply of timber products and corresponding effects on timber product markets are also highly relevant to Indicator 5.2.2 (Perez-Garcia et al., 2002; Kirilenko & Sedjo, 2007). The latter of those two will likely most affect corporate profits, as the dynamics of foreign forest product markets will fluctuate in response to these global increases in wood fibre.

- 2.2. Given expected changes in Canada's climate, describe if and how the indicator's ability to signal progress towards SFM remains unchanged.

The only likely influence of climate change on Indicator 5.2.2 arising from the impacts described above will be a slight decline in its predictability. These climate-change impacts are far more influential on other socioeconomic indicators, such as the volatility of future global forest product markets for Indicator 5.1.3 and the increase in salvage harvests for Indicator 5.3.1. The potential for this decline in predictability of Indicator 5.2.2 to significantly influence its SFM signal is low.

- 2.3. If an indicator's ability to signal progress towards SFM will be changed, describe if and how the indicator may become worse or better at signalling SFM progress.

Indicator 5.2.2 will not be significantly diminished in its ability to signal SFM progress under climate change.

3. Integrated Climate-Change Assessment

- 3.1. What are the key determinants of the indicator (i.e. what causes it to change when it does change);

a) Among other indicators in the C&I framework?

- **Employment and average income in the timber products sector are used to measure the financial benefits of employees, making Indicators 5.3.5, 6.3.3, and 5.3.6 determinants of Indicator 5.2.2.**
- **The profits of forest companies have historically been highly variable (CCFM, 2006), and are largely determined by Indicator 5.1.3.**
- **The financial benefits from stumpage fees received by governments are in-part determined by different timber tenure types, as tracked by Indicator 5.2.1.**

b) Among determinants not within the C&I framework?

- **Jurisdictional differences in taxes, stumpage fees, and the structure of public enterprises are all determinants of the financial benefits for governments.**

3.2. For what other entities is this indicator a key determinant (i.e. when it changes, what other indicators are influenced to change);

a) Among other indicators in the C&I framework?

- **Average income in major employment categories is in-part determined by Indicator 5.2.2.**
- **The distribution of financial benefits is a key determinant of the incidence of low income in forest-based communities, as tracked by Indicator 6.3.4.**

b) Among determinants not within the C&I framework?

- **The distribution of financial benefits from the timber products industry is a major driver of social equity for employees of the forest sector.**

3.3. To what degree can we now, on the basis of extant knowledge, establish how the key determinants interact cumulatively in influencing the indicator?

The distribution of financial benefits arising from the timber products sector that is tracked by Indicator 5.2.2 can be divided into three sections, which are cumulatively influenced by several determinants. The distribution of wages and salaries amongst employees of the timber products industry is primarily a function of employment rates and average incomes within the different subsectors, as tracked by Indicators 5.3.5 and 5.3.6,

respectively. The distribution of corporate profits are incredibly unstable, and are primarily determined by Indicator 5.1.3, which is in turned driven by a myriad of complex economic processes. Financial benefits received by governments depend on the cumulative interaction of the all those just mentioned, as well as the different jurisdictional policy and regulatory structures.

- 3.4. Is the indicator largely unrelated to any other, as described by the linkages assessment and evaluation of key determinants? If so, and the indicator was defined as uninfluenced by climate change in the independent assessment, then it can be placed in category one.

Indicator 5.2.2 is influenced by several different socioeconomic indicators, most of which are influenced by climate change. We therefore feel it would be imprudent to assign it to category one.

- 3.5. Do the indirect effects of climate change via the linkages with other indicators influence the indicator's ability to signal SFM, regardless of which category was assigned in the independent climate-change assessment?

The indirect effects of climate change on the supply of wood fibre and subsequently on global forest product markets, as tracked by Indicators 5.3.1 and 5.1.3, respectively, will likely cause a decline in the predictability of Indicator 5.2.2. However, we see no possible modifications to mitigate this decline, nor do we feel that it will significantly reduce the effectiveness of the Indicator.

- 3.6. If the indicator's ability to signal SFM progress remains the same under a changing climate, can we conclude no negative influence and leave it unchanged? These indicators can be placed in category two.

The ability of Indicator 5.2.2 to signal SFM progress will remain largely unchanged and it can be assigned to category two, *Unmodified Indicators*.

- 3.7. If the indicator's ability to signal SFM progress deteriorates when one assumes a changing climate, then what modifications are possible or warranted to improve its ability sufficiently for it to remain among the C&I-SFM? These indicators can be placed in category three.

Not applicable.

- 3.8. If no modifications seem possible or warranted, are we ready to recommend abandonment of the indicator? These indicators can be placed in category four.

Not applicable.

- 3.9. If we recommend abandonment, can we identify any new and closely allied indicators that might suit our needs better under climate change? Are there any other reasons for the creation of an additional indicator? These indicators can be placed in category five.

Not applicable.

- 3.10. Have extant climate-change impacts made this indicator more pertinent to SFM (i.e. 2.3 and the mountain pine beetle)? These indicators can be placed in category five or considered for conversion from a supporting to a core indicator (where applicable).

As with many other indicators in the C&I framework, the current outbreak of mountain pine beetle (*Dendroctonus ponderosae*) provides a perfect illustration of the observed impacts of climate change (Kurz et al., 2008). More pertinent to Indicator 5.2.2 are the socioeconomic impacts of this outbreak. For example, the community of Vanderhoof, British Columbia, is currently experiencing economic benefits from the salvage harvest operations in the region, including increases in household incomes of forest-sector workers (Williamson et al., 2008). However, these short-term benefits will certainly disappear as the supply beetle-infested pine becomes exhausted.

- 3.11. How should the surviving indicator (the original, modified, or new) be modelled and monitored so that stronger SFM signals may be generated?

The economic data used to measure Indicator 5.2.2 are all derived from Statistics Canada, except for real stumpage charges from 1990 to 2005, which are derived from the CCFM's National Forestry Database. Statistics Canada data include real wages and salaries for the logging, wood, and paper industries, real profits and real income taxes for the wood and paper industries, and total average financial benefits to labour, businesses, and government. Statistics Canada is a reliable future data source for monitoring Indicator 5.2.2 under climate change.

- 3.12. Does this indicator track an entity whose relationship with climate is regionally variable?

There will be some regional variability in the distribution of financial benefits from timber products sector under climate change.

INDICATOR 5.3.1 ANNUAL HARVEST OF TIMBER RELATIVE TO THE LEVEL OF HARVEST DEEMED TO BE SUSTAINABLE

1. Linkages Assessment

Table 1.1. Indicators influencing Indicator 5.3.1.

Indicator 5.3.1	Influencing Indicators
First order positive	2.5
First order negative	2.1 and 2.2
First order bi-directional	1.1.1, 1.3.1, 2.3, 3.3, 6.4.2, and 6.5.4

Table 1.2. Indicators influenced by Indicator 5.3.1.

Indicator 5.3.1	Influenced Indicators
First order positive	1.2.1, 2.3, 4.1.3, 4.1.4, 5.1.1, 5.1.2, 5.1.3, 5.3.5, and 6.3.3
First order negative	1.2.2, 1.2.3, 1.3.2, 2.1, 4.1.1, and 4.1.2
First order bi-directional	1.1.1, 2.5, 5.2.2, 5.3.4, and 6.3.1

- 1.1. Which indicators are influencing and influenced directly (first-order interactions) by the indicator in question? Is the indicator more of a driver of change in other indicators, or being driven by other indicators?

Indicator 5.3.1 is an incredibly influential indicator and is a vital link for the relationship between the biophysical and socioeconomic subsets of indicators. It influences 20 other indicators, from all Criteria except for Criterion 3. It is influenced by nine other indicators, again from both the biophysical and socioeconomic Criteria. Indicator 5.3.1 is far more of a driver of change than it is driven to change by other indicators.

- 1.2. List the indicators described as ‘relevant indicators under other criteria’ in the 2003 C&I-SFM. Is there any conflict with the interactions described in the matrix?

The sustainability of the social and economic benefits from SFM is highly dependent on the condition and productivity of forest ecosystems (Criteria 2), but also on decision-making processes that are relevant to the sustainable harvest of forest products, such as those tracked by Indicator 6.5.4. Indicators 5.3.1 and 5.3.2 are also described as highly relevant to forest-community well-being, tracked by indicators in Element 6.3.

- 1.3. Are there any overlaps or gaps in the relationship with indicators defined in Eddington and colleague’s (2009) report?

The FFEI project is focused on monitoring key species and ecological processes in order to signal and anticipate the response of forest and rangeland to climate change. There is no

inclusion of the socio-economic dimension of SFM, so there is no overlap between the C&I framework and the Eddington et al. (2009) report.

2. Independent Climate-Change Assessment

- 2.1. Provide in detail, a qualitative description of what are the expected direct effects of climate change on the indicator, using a broad representation from the literature.

There is an abundant number of ways in which climate change will affect Indicator 5.3.1. The predicted and observed increase in the frequency and severity of insect and disease outbreaks, wildfires, and extreme weather events are a more immediate threat to timber supplies and their sustainable management in Canada than other anticipated impacts (Dale et al., 2001; Flannigan et al., 2009; Williamson et al., 2009). In many regions, major losses to the timber supply can be expected to result from these disturbances (Johnston et al., 2010). This will also necessitate an increase in salvage harvests leading to more frequent incidences of exceeding allowable cuts (AAC) on Crown forest tenures, or even changes to AAC in response to major disturbance events (Volney & Fleming, 2000; Pederson, 2004; Spittlehouse, 2005; Lindenmayer & Noss, 2008). Another more immediate threat to the supply of timber is the decline in frozen-ground conditions and the length of the winter harvest season, which has major implications for operations in regions with wet, compaction-prone soils or poor accessibility (Barrow et al., 2004; Johnston et al., 2010).

In some regions and over a longer timeframe there may be potential benefits to the supply of timber. Changes in tree physiology and growth rates that are induced by climate-warming are anticipated to have a positive influence of forest productivity in many different region of Canada (Peng & Apps, 1999; Schimel et al., 2001; Bernier, 2007; Williamson et al., 2009). These effects may be amplified in regions where forest growth is regulated by temperature as it is in northern regions and high altitude ecosystems (Chaplin et al., 1995). On the national and international scale, it is widely speculated that there will be a net increase in the supply of wood fibre and, in some regions, an increase in harvest levels (Perez-Garcia et al., 2002; Kirilenko & Sedjo, 2007). However, it is predicted that Canada's relatively high cost of production of timber products and the global drop in prices in the forest sector may lead to declines in the national harvest rate (Perez-Garcia et al., 2002).

Forest ecosystem diversity is also predicted to be significantly influenced by the changing climate over the longer term. Forest composition and community distributions are expected to sustain considerable change over the next century, due primarily to climate-driven changes in tree species distributions (McKenney et al., 2007; Iverson et al., 2008). In more extreme cases along ecotones between forested and non-forested biomes there may be permanent changes in forest area due to dieback and treeline migration (Aitken et al., 2008; Hogg et al., 2008).

The future supply of timber and annual harvest rates in the end are highly uncertain and variable between regions, and will be fundamentally dependent on adaptive measures that

are incorporated into forest management (Johnston et al., 2010). We may also expect to adjustments to the rate of timber harvests as forest biomass continues to gain appreciation as a source of bioenergy (Hall, 2002).

- 2.2. Given expected changes in Canada's climate, describe if and how the indicator's ability to signal progress towards SFM remains unchanged.

Indicator 5.3.1 is a critical indicator within the C&I framework and represents a vital linkage between the biophysical and socioeconomic indicators. Its ability to signal SFM progress will be diminished by climate change.

- 2.3. If an indicator's ability to signal progress towards SFM will be changed, describe if and how the indicator may become worse or better at signalling SFM progress.

Indicator 5.3.1 will decline in its predictability and responsiveness under climate change. The AAC and subsequent harvest levels will be highly volatile at the regional scale due to the increasing frequency of major disturbance events and required salvage operations. However, this is a fundamental Indicator within the C&I framework due to both its high degree of interrelatedness and the high relevance of what it tracks. We see no possible or desirable alternatives or modifications to this Indicator.

3. Integrated Climate-Change Assessment

- 3.1. What are the key determinants of the indicator (i.e. what causes it to change when it does change);

- a) Among other indicators in the C&I framework?
- **The regulation of harvest levels on public lands with legislated requirements for individual licenses like AAC is a major determinant of Indicator 5.3.1 and harvest levels that are deemed sustainable in provincial jurisdictions. This makes Indicators 5.2.1 and 6.5.4 partial determinants.**
 - **The diversity of forest ecosystems is closely allied to timber supply, making Indicator 1.1.1 a determinant of Indicator 5.3.1.**
 - **The condition and productivity of forest ecosystems is a crucial determinant of timber supply, and Indicators as 2.1, 2.2, and 2.5 have a significant influence over the annual harvest of timber.**
 - **Natural disturbances are highly influential on the both the supply of timber and timber harvests, making Indicators 2.3 and 3.3 determinants of Indicator 5.3.1.**

- b) Among determinants not within the C&I framework?
- **The AAC also reflect societal values and political structures, as they influence timber tenure agreement on public land (CCFM, 2006).**
 - **The demand for forest products and market fluctuations, both domestic and foreign, will also influence the annual harvest of timber.**
- 3.2. For what other entities is this indicator a key determinant (i.e. when it changes, what other indicators are influenced to change);

- a) Among other indicators in the C&I framework?
- **Forest management and the harvest of timber are a major agent of change in managed forest landscapes and are a determinant of ecosystem, species, and genetic diversity, tracked by Indicators 1.1.1, 1.2.1, 1.2.2, 1.2.3, and 1.3.2.**
 - **Timber harvests will of course be a major determinant of the condition and productivity of managed forests and of Indicators 2.1, 2.3, and 2.5.**
 - **Indicator 5.3.1 is a determinant of the flux of carbon in forest ecosystems and the forest sector, as tracked by indicators in Criterion 4.**
 - **Indicator 5.3.1 is a key determinant among Indicators in Element 5.1 that track the economic benefits from SFM.**
 - **The annual harvest of timber from forest ecosystems is a key determinant for employment in the forest sector and forest community well-being, as tracked by Indicator 5.2.2 and those within Element 6.3.**

- b) Among determinants not within the C&I framework?
- **Indicator 5.3.1 tracks the annual harvest of timber, which is a core activity within SFM that has some degree of influence on all biophysical components of managed forest ecosystems and on the greater socioeconomic sphere of their management.**
- 3.3. To what degree can we now, on the basis of extant knowledge, establish how the key determinants interact cumulatively in influencing the indicator?

The most important interaction of these determinants is between the biophysical and socioeconomic categories. More specifically, Indicator 5.3.1 is determined by the biophysical factors that influence the availability of wood fibre, tracked by Indicators 1.1.1,

2.1, 2.3, and 2.5, and the socioeconomic ones that influence the determination of sustainable harvest levels, tracked by Indicators 5.2.1 and 6.5.4, as well as other social and political determinants external to the C&I framework. These two categories of determinants can at times be disparate, and it is more than likely that climate change will greatly obscure the socioeconomic and political factors that determine what sustainable harvest levels are.

- 3.4. Is the indicator largely unrelated to any other, as described by the linkages assessment and evaluation of key determinants? If so, and the indicator was defined as uninfluenced by climate change in the independent assessment, then it can be placed in category one.

Indicator 5.3.1 is a highly influential indicator and is the most interrelated of the socioeconomic indicator subset. It should not be assigned to category one.

- 3.5. Do the indirect effects of climate change via the linkages with other indicators influence the indicator's ability to signal SFM, regardless of which category was assigned in the independent climate-change assessment?

Indicator 5.3.1 is primary influenced by climate change indirectly. The most important linkages with other indicators within the C&I framework under climate change will likely be with Indicators 1.1.1, 2.1, 2.2, 2.3, and 2.5. These Indicators will be affected by the predicted changes in natural disturbance regimes, forest productivity, and forest composition, and will consequently influence the timber supply and the rate harvest that is sustainable (Williamson et al., 2009; Johnston et al., 2010).

- 3.6. If the indicator's ability to signal SFM progress remains the same under a changing climate, can we conclude no negative influence and leave it unchanged? These indicators can be placed in category two.

Indicator 5.3.1 will be diminished due to a considerable decline in predictability and a smaller decline in responsiveness. However, this Indicator is at the core of SFM in Canada, and we see no possible modifications or alternative indicators to alleviate these declines. A major emphasis was placed on AAC levels for hardwood and softwood on Crown forest tenures and on an estimated total AAC for Canada in the most recent C&I-SFM assessment (CCFM, 2006). Our ability to approximate levels of sustainable harvest or AAC as a surrogate for sustainability is a more volatile variable than total harvest alone, and we initially considered modifying Indicators 5.3.1 and 5.3.2 to track total harvest volume only. After some deliberation, we concluded that AAC is so embedded forest tenures and does have the potential to reflect the changing climate, given the modifications to Indicator 5.2.1 and new indicators created in Criteria 1 and 2, that assigning it to the *Unmodified Indicators* category was the best course of action.

- 3.7. If the indicator's ability to signal SFM progress deteriorates when one assumes a changing climate, then what modifications are possible or warranted to improve its ability sufficiently for it to remain among the C&I-SFM? These indicators can be placed in category three.

Not applicable. Despite the decline in this Indicator's effectiveness, we do not recommend modifying it.

- 3.8. If no modifications seem possible or warranted, are we ready to recommend abandonment of the indicator? These indicators can be placed in category four.

Not applicable. We do not recommend abandoning this highly valuable and influential Indicator.

- 3.9. If we recommend abandonment, can we identify any new and closely allied indicators that might suit our needs better under climate change? Are there any other reasons for the creation of an additional indicator? These indicators can be placed in category five.

Not applicable.

- 3.10. Have extant climate-change impacts made this indicator more pertinent to SFM (i.e. 2.3 and the mountain pine beetle)? These indicators can be placed in category five or considered for conversion from a supporting to a core indicator (where applicable).

The recent outbreak of mountain pine beetle (*Dendroctonus ponderosae*) in British Columbia and Alberta has surpassed all previous ones in severity and extent, and has been attributed in-part to climate change and the shortage of limiting winter temperatures (Kurz et al., 2008). The AAC and harvest rates were subsequently raised in central British Columbia in an attempt to salvage some of the millions of cubic metres of infested wood (Pederson et al., 2004). For a more detailed description of this highly pertinent impact of climate change see the evaluation of Indicator 2.3.

- 3.11. How should the surviving indicator (the original, modified, or new) be modelled and monitored so that stronger SFM signals may be generated?

The primary source for data on timber harvest levels (softwood, hardwood, and total) is the National Forestry Database, which is a database of national forestry statistics created by the CCFM (CCFM, 2010). This database will remain essential to future measurement of Indicator 5.3.1. However, a challenging task for the future monitoring of this Indicator will be the measurement of annual harvest levels on private, territorial, and federal lands.

3.12. Does this indicator track an entity whose relationship with climate is regionally variable?

There will be regional implications for the annual harvest of timber in Canada under climate change.

INDICATOR 5.3.2 ANNUAL HARVEST OF NON-TIMBER FOREST PRODUCTS RELATIVE TO THE LEVEL OF HARVEST DEEMED TO BE SUSTAINABLE

1. Linkages Assessment

Table 1.1. Indicators influencing Indicator 5.3.2.

Indicator 5.3.2	Influencing Indicators
First order positive	1.2.2 and 1.2.3
First order negative	2.2
First order bi-directional	1.1.1, 1.1.2, 2.1, 2.3, 2.5, 3.3, 6.4.2, and 6.5.4

Table 1.2. Indicators influenced by Indicator 5.3.2.

Indicator 5.3.2	Influenced Indicators
First order positive	1.2.1, 4.1.3, 4.1.4, 5.1.4, 5.1.5, 5.3.5, 6.3.1, and 6.3.3
First order negative	1.2.2 and 1.2.3
First order bi-directional	1.1.1, 1.1.2, 2.1, 4.1.1, 4.1.2, and 5.2.2

- 1.1. Which indicators are influencing and influenced directly (first-order interactions) by the indicator in question? Is the indicator more of a driver of change in other indicators, or being driven by other indicators?

Indicator 5.3.2 is directly influenced by 11 other indicators, primarily from Criteria 1 and 2. It influences 16 other indicators within the C&I framework, from all Criteria excepting Criterion 3. As for both its influence on other indicators and the level of influence from other indicators, Indicator 5.3.2 (aside from Indicator 5.3.1) is possibly the most influential of the socioeconomic indicators. It is especially important as a link between the biophysical indicators and the remaining socioeconomic indicators. It is more of a driver of change than driven to change.

- 1.2. List the indicators described as ‘relevant indicators under other criteria’ in the 2003 C&I-SFM. Is there any conflict with the interactions described in the matrix?

The sustainability of the benefits derived from forest ecosystems is fundamentally linked to the condition and productivity of those ecosystems. Thus, Criteria 2, and Indicators 2.3, 2.4, and 2.5, are especially relevant to Indicator 5.3.2. Investment in forest research, timber products industry research and development, and education (Indicator 6.5.3) also has a positive influence on the sustainability of non-timber forest products (NTFP). Indicators 5.3.2 and 5.3.1 are described as highly relevant to forest-community well-being, tracked by indicators within Element 6.3.

- 1.3. Are there any overlaps or gaps in the relationship with indicators defined in Eddington and colleague’s (2009) report?

The FFEI project is focused on monitoring key species and ecological processes in order to signal and anticipate the response of forest and rangeland to climate change. There is no inclusion of the socio-economic dimension of SFM, so there is no overlap between the C&I framework and the Eddington et al. (2009) report.

2. Independent Climate-Change Assessment

- 2.1. Provide in detail, a qualitative description of what are the expected direct effects of climate change on the indicator, using a broad representation from the literature.**

NTFP are a very diverse and inclusive aggregation of ecosystem services that range from more tangible products like wild edible berries, mushrooms, and maple products to complex and labour-intensive biotechnologies to the less-tangible carbon credits (Duchesne & Wetzel, 2002; CCFM, 2006). NTFP and related harvesting activities are a vital component of social and economic sustainability, especially within rural, forest-dependent communities and Aboriginal communities, as they often provide a means of income and economic diversity where such things are scarce (Hardy, 2002). However, the NTFP sector is still a young and developing sector of the economy that is occasionally believed to be at odds with the timber products sector (Duchesne & Wetzel, 2002). It is in need of regulation and pertinent policies addressing its sustainable development (CCFM, 2006).

There are few if any intensive studies on the implications of climate change for the sustainable flow of NTFP and forest-based services in Canada. However, it is recognized that these valuable resources will most likely suffer adverse effects in the coming years (Johnston et al., 2010). All NTFP are in some way linked to the health of a forest and its biological diversity (Hauer et al., 2001; Johnston et al., 2010). For this reason, they will be vulnerable to climate change because ecosystem, species, and genetic diversity are all threatened (Gray, 2005).

The maple products industry is by far the biggest contributor to the total estimated value of NTFP (CCFM, 2006), and provides a useful illustration for the interaction of NTFP with climate change. The changing climate may affect this industry to varying degrees and in divergent directions. In the short term, extreme weather and more frequent thaw-freeze events will most likely hinder and reduce the sustainable harvest of these products. For example, the ice storm of 1998 was the largest ever recorded and decimated the maple product industry in eastern Canada and the northeastern United States (Irland, 1998; Kerry et al., 1999). Conversely, over the long term it is predicted that the northward shifting range of sugar maple (*Acer saccharum*) will make it climatically favoured over a greater area in eastern Canada (McKenney et al., 2007).

- 2.2. Given expected changes in Canada's climate, describe if and how the indicator's ability to signal progress towards SFM remains unchanged.**

The ability of Indicator 5.3.2 to signal SFM progress will be influenced and most likely diminished by climate change.

- 2.3. If an indicator's ability to signal progress towards SFM will be changed, describe if and how the indicator may become worse or better at signalling SFM progress.

Indicator 5.3.2 will decline in its ability to signal SFM progress under climate change. The aforementioned influences of climate change on the annual harvest of NTFP and its sustainability illustrates a critical question: what level of harvest is sustainable? The extent to which climate change is predicted to affect forest ecosystems and the biological diversity they contain will mask the level of NTFP harvest that is sustainable, which is further complicated by the highly diverse nature of NTFP. However, this is a fundamental Indicator within the C&I framework, and as with Indicator 5.3.1, we see no possible or desirable alternatives or modifications to this Indicator. There may be some opportunities to improve the feasibility and relevance of this Indicator, as NTFP are becoming an increasingly recognized subsector, and will hopefully spur more comprehensive data collection.

3. Integrated Climate-Change Assessment

- 3.1. What are the key determinants of the indicator (i.e. what causes it to change when it does change);

- a) Among other indicators in the C&I framework?
 - **A slew of biophysical indicators from Criteria 1 and 2 are major determinants of the supply of NTFP and, where applicable, their habitat, as sustainable harvests of NTFP are dependent on forest biodiversity and the health of forest ecosystems.**
 - **The compliance of NTFP harvests with applicable sustainable forest management laws and regulations (Indicator 6.4.2) is also relevant for Indicator 5.3.2.**
 - **The development or upgrade of standards and guidelines pertaining to NTFP activities, as tracked by Indicator 6.5.4 is influential on Indicator 5.3.2.**
- b) Among determinants not within the C&I framework?
 - **The growing recognition of NTFP industries as a viable economic sector and the importance of NTFP-related activities to rural, forest-dependent communities and Aboriginal peoples are likely contributing to the expansion of the NTFP sector and increases in harvest levels.**

3.2. For what other entities is this indicator a key determinant (i.e. when it changes, what other indicators are influenced to change);

a) Among other indicators in the C&I framework?

- **The annual harvest of NTFP and its sustainability is dependent of forest ecosystems, but can also be influential on forest ecosystem, species, and genetic diversity, tracked by Indicators 1.1.1, 1.2.1, 1.2.2, and 1.2.3.**
- **The harvest of some NTFP, such as Christmas trees, can be a determinant of the condition and productivity of forest ecosystems, and indicators within Criterion 2.**
- **Indicator 5.3.2 is a determinant of the flux of carbon in the forest sector, as tracked by indicators in Criterion 4, though to a much smaller degree than Indicator 5.3.1.**
- **Indicator 5.3.2 is the key determinant for indicators in Element 5.1 that track the economic benefits from the NTFP sector, inducing Indicators 5.1.4 and 5.1.5.**
- **The annual harvest of NTFP is a determinant of forest-sector employment, especially in forest-dependent communities, making Indicator 5.3.2 an important determinant for indicators in Element 6.3.**

b) Among determinants not within the C&I framework?

- **Indicator 5.3.2 monitors NTFP harvest activity and the sustainability of harvests, which are growing in recognition and economic value within the forest sector (CCFM, 2006). It is a highly influential indicator and like Indicator 5.3.1 it is an important intermediary between the biophysical and socioeconomic CCFM indicators. The full value of NTFP to Aboriginal peoples and rural communities with fewer economic opportunities cannot be fully captured within the C&I framework.**

3.3. To what degree can we now, on the basis of extant knowledge, establish how the key determinants interact cumulatively in influencing the indicator?

The harvest of NTFP is affected cumulatively by all agents of change that affect biological diversity and forest-ecosystem condition and productivity. The cumulative effects of land-use change, habitat alteration and loss, and the introduction of invasive, alien, forest-associated species will all influence the supply of NTFP. For example, habitat modification on a Christmas tree farm or in a commercial sugar bush will adversely affect populations of fur-bearing mammals and the abundance of wild edible plants. The annual harvest of NTFP is also influenced by the cumulative, socioeconomic effects of varying consumer demand, international trade, and market stability.

- 3.4. Is the indicator largely unrelated to any other, as described by the linkages assessment and evaluation of key determinants? If so, and the indicator was defined as uninfluenced by climate change in the independent assessment, then it can be placed in category one.

Indicator 5.3.2, along with 5.3.1, is the most interrelated of the socioeconomic indicators, and a crucial intermediary for the interactions between other socioeconomic indicators and the biophysical indicators. We do not recommend assigning it to category one.

- 3.5. Do the indirect effects of climate change via the linkages with other indicators influence the indicator's ability to signal SFM, regardless of which category was assigned in the independent climate-change assessment?

The annual harvest of NTFP and its sustainability will almost be entirely affected by climate change indirectly. These indirect effects include changes in the population dynamics of forest-associated species and declines in ecosystem, species, and genetic diversity (Thomas et al., 2004; Gray, 2005), more frequent and severe natural disturbances (Dale et al., 2001; Williamson et al., 2009), and changes in forest productivity, composition, and area (McKenney et al., 2007; Williamson et al. 2009).

- 3.6. If the indicator's ability to signal SFM progress remains the same under a changing climate, can we conclude no negative influence and leave it unchanged? These indicators can be placed in category two.

Indicator 5.3.2 has some existing challenges with its feasibility and relevance, as was evident in the 2005 national assessment (CCFM, 2006). Moreover, climate change will further challenge the predictability and responsiveness of this Indicator. However, like Indicator 5.3.1, Indicator 5.3.2 is a critical indicator in the C&I framework, and is especially important for rural and Aboriginal communities. Again like Indicator 5.3.1, we expect that some of the decline in indicator effectiveness will be mitigated by the new and modified indicators in Criteria 1 through 4, as Indicator 5.3.2 is influenced indirectly by climate change through many of these indicators. Consequently, we assigned it to category two, *Unmodified Indicators*.

- 3.7. If the indicator's ability to signal SFM progress deteriorates when one assumes a changing climate, then what modifications are possible or warranted to improve its ability sufficiently for it to remain among the C&I-SFM? These indicators can be placed in category three.

Not applicable. We do not recommend modifying Indicator 5.3.1.

- 3.8. If no modifications seem possible or warranted, are we ready to recommend abandonment of the indicator? These indicators can be placed in category four.

Not applicable. We do not recommend abandoning this highly insightful and influential Indicator.

- 3.9. If we recommend abandonment, can we identify any new and closely allied indicators that might suit our needs better under climate change? Are there any other reasons for the creation of an additional indicator? These indicators can be placed in category five.

Not applicable.

- 3.10. Have extant climate-change impacts made this indicator more pertinent to SFM (i.e. 2.3 and the mountain pine beetle)? These indicators can be placed in category five or considered for conversion from a supporting to a core indicator (where applicable).

Climate change is already blamed for much of the recent severe weather events. One such example is the series of ice storms that devastated human infrastructure and forest ecosystems from Ontario to Nova Scotia in January of 1998 (Irland, 1998). It is estimated that 12.5% of sugar maple taps in Ontario were destroyed (McCready, 2004). Quebec is the world's largest exporter of maple products, and it was estimated that they lost somewhere between 2.8 and 3.0 million taps, around 10% of the total (Kerry et al., 1999).

- 3.11. How should the surviving indicator (the original, modified, or new) be modelled and monitored so that stronger SFM signals may be generated?

The incredibly diverse types and sources of NTFP in Canada and the fact that the majority of them originate on private land (CCFM, 2006) make it exceedingly difficult to collect data on the total annual harvests. Future C&I-SFM assessments will likely have to rely on organizations and research institutions for NTFP data like those described in the 2005 assessment. However, it is hoped that with the increasing strength of the NTFP sector, emergent jurisdiction and territorial policies and regulations will make future assessments of Indicator 5.3.2 more feasible than previous ones.

Professional associations like the Ontario Maple Syrup Producers Association and the Fédération des Producteurs Acéricoles du Québec or the Canadian Christmas Tree Growers Association could provide valuable insights into some of the larger NTFP subsectors for case studies in future assessments, if not quantitative data.

- 3.12. Does this indicator track an entity whose relationship with climate is regionally variable?

There will be regional implications for the annual harvest of different NTFP in Canada under climate change.

INDICATOR 5.3.3 RETURN ON CAPITAL EMPLOYED

1. Linkages Assessment

Table 1.1. Indicators influencing Indicator 5.3.3.

Indicator 5.3.3	Influencing Indicators
First order positive	5.1.1, 5.1.2, 5.1.4, and 6.5.3
First order negative	None
First order bi-directional	5.1.3

Table 1.2. Indicators influenced by Indicator 5.3.3.

Indicator 5.3.3	Influenced Indicators
First order positive	6.5.3
First order negative	None
First order bi-directional	None

- 1.1. Which indicators are influencing and influenced directly (first-order interactions) by the indicator in question? Is the indicator more of a driver of change in other indicators, or being driven by other indicators?

Indicator 5.3.3 is influenced by five other indicators, most pertaining to the economic benefits from Element 5.1. It influences just one other, Indicator 6.5.3, which also influences it. Indicator 5.3.3 is marginally more driven to change than it is a driver of change for other indicators.

- 1.2. List the indicators described as ‘relevant indicators under other criteria’ in the 2003 C&I-SFM. Is there any conflict with the interactions described in the matrix?

There is little mention of the relevance of Indicator 5.3.3 to other indicators within the C&I framework specifically. However, investment in forest research, timber products industry research and development, and education (Indicator 6.5.3) is described as relevant for the sustainability of the benefits from SFM and Indicator 5.3.3. This is in agreement with the interaction matrix. However, return on capital employed (ROCE) and Indicator 5.3.3 were also found to in fact influence the likelihood of capital investment in different industries (CCFM, 2006).

- 1.3. Are there any overlaps or gaps in the relationship with indicators defined in Eddington and colleague’s (2009) report?

The FFEI project is focused on monitoring key species and ecological processes in order to signal and anticipate the response of forest and rangeland to climate change. There is no inclusion of the socio-economic dimension of SFM, so there is no overlap between the C&I framework and the Eddington et al. (2009) report.

2. Independent Climate-Change Assessment

- 2.1. Provide in detail, a qualitative description of what are the expected direct effects of climate change on the indicator, using a broad representation from the literature.

The ROCE of an industry or subsector within the forest sector is measured as the ratio of their net revenues (earnings before interest and taxes) divided by net assets (assets minus liabilities). This statistic is widely used in economics to determine the financial health of an industry or sector of the economy. Canada performed relatively poorly in comparison with other major producers of forest products, such as the United States, Sweden, and Finland, which is in part attributed to the high cost of production of some of Canada's industries, particularly pulp and paper (CCFM 2006).

It was predicted that nations with higher costs of production will be economically stressed within future global forest product markets under climate change because of the increase in global supply of wood fibre and corresponding price drops (Perez-Garcia et al., 2002). Globalization and a stronger reliance on the relative abundance of inexpensive labour and raw materials in tropical regions will also adversely affect forest sectors in more developed countries like Sweden and Canada (Jonsson, 2009). In the short term, more frequent and severe natural disturbances (Dale et al., 2001) are expected to drive potential declines in the supply of wood fibre, while over the longer term it is believed that there will be global increases in wood fibre because of the effects of climate change on forest productivity (Kirilenko & Sedjo, 2007). Moreover, future policies around climate-change mitigation may positively affect the economic welfare of forest product markets by increasing the demand for less carbon-intensive materials derived from forests (Jonsson, 2009). However, it must be made abundantly clear that the combination of economic, ecological, and climatic prediction make this an incredibly uncertain topic.

- 2.2. Given expected changes in Canada's climate, describe if and how the indicator's ability to signal progress towards SFM remains unchanged.

The relevance of ROCE to the economic benefits and sustainability of SFM remains untouched by climate change, as does its measurability. The marginal decline in its predictability does not diminish the strength of the SFM signal generated by Indicator 5.3.3, nor its ability to track SFM progress.

- 2.3. If an indicator's ability to signal progress towards SFM will be changed, describe if and how the indicator may become worse or better at signalling SFM progress.

The predictability of Indicator 5.3.3 may decline slightly because of some of the anticipated effects of climate change on the economic welfare of the forest sector in Canada, in addition to the uncertainty of future global forest product markets. However, we do not feel that this diminishes the ability of the Indicator to any great degree.

3. Integrated Climate-Change Assessment

3.1. What are the key determinants of the indicator (i.e. what causes it to change when it does change);

a) Among other indicators in the C&I framework?

- **The economic value of forest products, tracked by Indicators 5.1.1, 5.1.2, and 5.1.4, and forest sector activity, tracked by Indicator 5.1.3, are all key determinants of Indicator 5.3.3.**
- **Investment in forest product industry research and development, tracked by Indicator 6.5.3, is a determinant of Indicator 5.3.3.**

b) Among determinants not within the C&I framework?

- **A firm's or an industry's assets, liabilities, and profitability, calculated with earnings before interest and taxes (EBIT), are all used in measuring Indicator 5.3.3 and are valid determinants.**
- **The strength of domestic and international markets for forest products is a determinant of Indicator 5.3.3, as the ROCE of many forest product industries has varied considerably in the past at times of recession (CCFM, 2006).**

3.2. For what other entities is this indicator a key determinant (i.e. when it changes, what other indicators are influenced to change);

a) Among other indicators in the C&I framework?

- **ROCE is a determinant of the likelihood of private capital investment in an industry, which is a component of Indicator 6.5.3 (CCFM, 2006).**

b) Among determinants not within the C&I framework?

- **The economic health and welfare of forest subsectors, individual industries, and firms are determined by their ROCE.**
- **ROCE can also provide a measure of an industry's international competitiveness, which is external to the C&I framework.**

3.3. To what degree can we now, on the basis of extant knowledge, establish how the key determinants interact cumulatively in influencing the indicator?

Cumulative effects on the ROCE and profitability of different industries within the forest sector are largely related to domestic and international markets and economies, which are exceedingly complex and unpredictable. However, the role of Indicator 5.1.3 in determining Indicator 5.3.3 is likely more pronounced than that of all other determinants. Under climate change, the role of these determinants in influencing Indicator 5.3.3 will likely become increasingly unpredictable.

- 3.4. Is the indicator largely unrelated to any other, as described by the linkages assessment and evaluation of key determinants? If so, and the indicator was defined as uninfluenced by climate change in the independent assessment, then it can be placed in category one.

Indicator 5.3.3 is relatively unrelated to other indicators within the C&I framework. The marginal decline in the predictability of the indicator does not surmount to any substantial decline in the strength of the SFM signal generated by the Indicator, and we therefore feel it safe to assign it to category one, *Uninfluenced Indicators*.

- 3.5. Do the indirect effects of climate change via the linkages with other indicators influence the indicator's ability to signal SFM, regardless of which category was assigned in the independent climate-change assessment?

The key interactions of climate change with Indicator 5.3.3 are via Indicators 2.1 and 2.3 and pertain to the climate-induced changes in forest productivity and natural disturbance regimes. These will subsequently affect Indicators 5.3.1 and 5.1.3, and therefore very remotely affect Indicator 5.3.3. The degree to which this climate-change influence is removed from Indicator 5.3.3 reinforces our assignment to category one.

- 3.6. If the indicator's ability to signal SFM progress remains the same under a changing climate, can we conclude no negative influence and leave it unchanged? These indicators can be placed in category two.

Not applicable. Indicator 5.3.3 is functionally uninfluenced by climate change.

- 3.7. If the indicator's ability to signal SFM progress deteriorates when one assumes a changing climate, then what modifications are possible or warranted to improve its ability sufficiently for it to remain among the C&I-SFM? These indicators can be placed in category three.

Not applicable.

- 3.8. If no modifications seem possible or warranted, are we ready to recommend abandonment of the indicator? These indicators can be placed in category four.

Not applicable.

- 3.9. If we recommend abandonment, can we identify any new and closely allied indicators that might suit our needs better under climate change? Are there any other reasons for the creation of an additional indicator? These indicators can be placed in category five.

Not applicable.

- 3.10. Have extant climate-change impacts made this indicator more pertinent to SFM (i.e. 2.3 and the mountain pine beetle)? These indicators can be placed in category five or considered for conversion from a supporting to a core indicator (where applicable).

There are no extant examples of climate change that make the return on capital employed a more relevant statistic or Indicator of SFM. Documented changes in forest productivity and natural disturbances regimes (Williamson et al., 2009) and their implications for the economic benefits and sustainability of the forest sector are far more pertinent to Indicators 5.1.3 and 5.3.1.

- 3.11. How should the surviving indicator (the original, modified, or new) be modelled and monitored so that stronger SFM signals may be generated?

The subsectors that are monitored under Indicator 5.3.3 include wood pulp, newsprint and uncoated mechanical printing paper, other papers and boards, lumber and logging, and panels (CCFM, 2006). Statistics Canada does not subdivide ROCE data beyond the wood and paper subsectors, so several different data sources were drawn from in the 2005 C&I-SFM assessment (CCFM, 2006). Most notable of these were reports from the Forest Products Association and Pricewaterhouse Coopers. Unfortunately, due to differences in methodologies, comparisons between the data may be tentative and uncertain. However, the only other measurable approach to this would be to consult with individual firms, which would not be feasible at the national scale.

- 3.12. Does this indicator track an entity whose relationship with climate is regionally variable?

The regional variability in climate-change impacts does not affect the SFM signal generated by Indicator 5.3.3.

INDICATOR 5.3.4 *PRODUCTIVITY INDEX*

1. Linkages Assessment

Table 1.1. Indicators influencing Indicator 5.3.4.

Indicator 5.3.4	Influencing Indicators
First order positive	6.3.2 and 6.5.3
First order negative	None
First order bi-directional	5.1.3 and 5.3.1

Table 1.2. Indicators influenced by Indicator 5.3.4.

Indicator 5.3.4	Influenced Indicators
First order positive	None
First order negative	5.3.5 and 6.3.3
First order bi-directional	None

- 1.1. Which indicators are influencing and influenced directly (first-order interactions) by the indicator in question? Is the indicator more of a driver of change in other indicators, or being driven by other indicators?

Indicator 5.3.4 is influenced by four other indicators and influences two others, all from Criteria 5 and 6. It is largely unrelated to other indicators within the C&I framework, and is neither a major driver of change or driven to change by other indicators.

- 1.2. List the indicators described as ‘relevant indicators under other criteria’ in the 2003 C&I-SFM. Is there any conflict with the interactions described in the matrix?

There is no specific description of the relevance of Indicator 5.3.4 to other indicators within the C&I framework. However, investment in forest research, timber products industry research and development, and education (Indicator 6.5.3) is described as highly relevant for the sustainability of the benefits from SFM. This is supported by the findings in the interaction matrix.

- 1.3. Are there any overlaps or gaps in the relationship with indicators defined in Eddington and colleague’s (2009) report?

The FFEI project is focused on monitoring key species and ecological processes in order to signal and anticipate the response of forest and rangeland to climate change. There is no inclusion of the socio-economic dimension of SFM, so there is no overlap between the C&I framework and the Eddington et al. (2009) report.

2. Independent Climate-Change Assessment

- 2.1. Provide in detail, a qualitative description of what are the expected direct effects of climate change on the indicator, using a broad representation from the literature.

Indicator 5.3.4 monitors changes in the productivity of the logging and forestry, wood, and paper subsectors, which is the ratio of output of manufactured forest products to production inputs, such as labour, capital, and wood fibre (CCFM, 2006). The key interaction of productivity of the monitored forest subsectors with climate change will be through changes in the supply and quality of wood fibre used in the production of timber products. The effects of declining wood quality have already been seen in the 1990s, when the logging industry was forced to harvest greater proportions of second-growth forest (CCFM, 2006). It is often held that this higher reliance on second-growth in place of old-growth has been a driver in the decline in wood quality because of the greater number of younger trees with higher proportions of juvenile wood (Jozsa & Middleton, 1994; Kennedy, 1995). More frequent and severe fires, extreme weather events, and outbreaks of insects and disease (Francis & Hengeveld, 1998; Williamson et al., 2009) will not only lead to a decline in the supply of wood fibre (Johnston et al., 2010), but also a decline in its quality, as wood that is exposed to drought, severe winds, or that is infected with insects or disease will often be cracked, split, more resinous, warped, or twisted (Nyland, 1996; Parker et al., 2000). This will likely have some implications for the future productivities of the monitored forest subsectors.

- 2.2. Given expected changes in Canada's climate, describe if and how the indicator's ability to signal progress towards SFM remains unchanged.

The ability of Indicator 5.3.4 to signal SFM progress pertaining to the sustainability of the social and economic benefits from the forest sector is largely uninfluenced by climate change. It is an easily measured and understandable Indicator, and the marginal decline in its predictability due to the impacts of climate change on forest-ecosystem condition and productivity does not diminish the strength of the SFM signal generated by Indicator 5.3.3 by any significant amount.

- 2.3. If an indicator's ability to signal progress towards SFM will be changed, describe if and how the indicator may become worse or better at signalling SFM progress.

The predictability of Indicator 5.3.4 may be marginally diminished by climate change. However, it is far enough removed from the influence of climate change that its overall ability to signal SFM progress will be uninfluenced.

3. Integrated Climate-Change Assessment

3.1. What are the key determinants of the indicator (i.e. what causes it to change when it does change);

a) Among other indicators in the C&I framework?

- **Investment in forest products research and development is a major driver of productivity, making Indicator 6.5.3 a key determinant of Indicator 5.3.4.**
- **The flow of wood fibre (Indicator 5.3.1) and its quality and the production of timber products (Indicator 5.1.3) are important determinants of Indicator 5.3.4.**
- **Education levels of workers, as tracked by Indicator 6.3.2, are also a determinant of labour productivity and growth.**

b) Among determinants not within the C&I framework?

- **The regulatory environment is important for labour productivity and growth, as stricter environmental regulations recently have been in part attributed to declines in productivity in the 1990s (CCFM, 2006).**
- **The condition of forest ecosystems and subsequently of wood fibre is an important determinant of how productive manufacturing is. While this is of course represented by Criterion 2, it is not a direct linkage as defined in the interaction matrix.**
- **The continual development of new technology and refinement of existing technology, such as reducing sawmill blade kerfs (CCFM, 2006), are important determinants of productivity.**

3.2. For what other entities is this indicator a key determinant (i.e. when it changes, what other indicators are influenced to change);

a) Among other indicators in the C&I framework?

- **Growth in labour productivity, especially that achieved by the introduction of new technology, can lead to job loss, making Indicator 5.3.4 a partial determinant of Indicators 5.3.5 and 6.3.3.**

b) Among determinants not within the C&I framework?

- **The economic health and welfare of forest subsectors and their competitiveness are partially determined by Indicator 5.3.4, especially their competitiveness in global markets (CCFM, 2006).**

3.3. To what degree can we now, on the basis of extant knowledge, establish how the key determinants interact cumulatively in influencing the indicator?

The most important interaction of the determinants of Indicator 5.3.4 is most likely the declining quality of wood fibre that must now be derived mainly from second-growth forests, the continual improvement of timber-production technology, and the increasing burden from stricter environmental regulations. The cumulative influence of this interaction is fairly uncertain, and drives the productivity index of forest-products subsectors in either direction.

3.4. Is the indicator largely unrelated to any other, as described by the linkages assessment and evaluation of key determinants? If so, and the indicator was defined as uninfluenced by climate change in the independent assessment, then it can be placed in category one.

Indicator 5.3.4 is relatively unrelated to other Indicators in the C&I framework, and is certainly not a major agent of change. The influence of climate change on the productivity index of the logging and forestry, wood, and paper subsectors will be only marginally influenced by climate change, if at all. We recommend assigning it to category one, *Uninfluenced Indicators*.

3.5. Do the indirect effects of climate change via the linkages with other indicators influence the indicator's ability to signal SFM, regardless of which category was assigned in the independent climate-change assessment?

The most important influence of climate change for Indicator 5.3.4 will be the increase in natural-disturbance frequency and severity, especially in the short term. These impacts on the supply of wood fibre, tracked by Indicator 2.1, and the sustainable flow of timber, tracked by Indicator 5.3.1, will have some influence on the predictability of Indicator 5.3.4.

3.6. If the indicator's ability to signal SFM progress remains the same under a changing climate, can we conclude no negative influence and leave it unchanged? These indicators can be placed in category two.

Not applicable. The Indicator has already been assigned to category one.

3.7. If the indicator's ability to signal SFM progress deteriorates when one assumes a changing climate, then what modifications are possible or warranted to improve its ability

sufficiently for it to remain among the C&I-SFM? These indicators can be placed in category three.

Not applicable

- 3.8. If no modifications seem possible or warranted, are we ready to recommend abandonment of the indicator? These indicators can be placed in category four.

Not applicable.

- 3.9. If we recommend abandonment, can we identify any new and closely allied indicators that might suit our needs better under climate change? Are there any other reasons for the creation of an additional indicator? These indicators can be placed in category five.

Not applicable.

- 3.10. Have extant climate-change impacts made this indicator more pertinent to SFM (i.e. 2.3 and the mountain pine beetle)? These indicators can be placed in category five or considered for conversion from a supporting to a core indicator (where applicable).

There are no examples of studies exploring the influence of some of the major climate-change impacts in Canada, such as the mountain pine beetle (*Dendroctonus ponderosae*) outbreak in western Canada and aspen (*Populus* spp.) dieback in the prairie provinces (Hogg & Bernier, 2006; Kurz et al., 2008), on the productivity index of the forest sector.

- 3.11. How should the surviving indicator (the original, modified, or new) be modelled and monitored so that stronger SFM signals may be generated?

Indicator 5.3.4 was measured using data from the Centre for the Study of Living Standards (CSLS) that has analyzed labour productivity grown the forestry and logging, wood, and paper subsectors since 1961 (CSLS, 2004; CCFM, 2006). The CSLS is a non-profit, independent organization that conducts economic and social well-being research in Canada, which is still active and will likely prove to be a valuable source for the continual monitoring of Indicator 5.3.4.

- 3.12. Does this indicator track an entity whose relationship with climate is regionally variable?

The productivity index may be slightly sensitive to the regional impacts of climate change on forest-ecosystem condition and productivity, but this will not overly influence the SFM signal generated by Indicator 5.3.4.

INDICATOR 5.3.5 *DIRECT, INDIRECT AND INDUCED EMPLOYMENT*

1. Linkages Assessment

Table 1.1. Indicators influencing Indicator 5.3.5.

Indicator 5.3.5	Influencing Indicators
First order positive	5.1.3, 5.3.1, 5.3.2, and 6.3.1
First order negative	5.3.4
First order bi-directional	5.2.1

Table 1.2. Indicators influenced by Indicator 5.3.5.

Indicator 5.3.5	Influenced Indicators
First order positive	6.3.3
First order negative	6.3.4
First order bi-directional	5.2.1, 5.2.2, 5.3.6, and 6.3.1

- 1.1. Which indicators are influencing and influenced directly (first-order interactions) by the indicator in question? Is the indicator more of a driver of change in other indicators, or being driven by other indicators?

Indicator 5.3.5 is influenced by six indicators, all from Criterion 5 except Indicator 6.3.1. It influences six other indicators from Criteria 5 and 6. Indicator 6.3.3 is not overly related to other indicators, and is both a driver of change and driven to change by other indicators.

- 1.2. List the indicators described as ‘relevant indicators under other criteria’ in the 2003 C&I-SFM. Is there any conflict with the interactions described in the matrix?

The economic welfare of the forest sector, including the employment that it generates, is dependent on the condition, productivity, and diversity of forest ecosystems (i.e. Criteria 1 and 2). The employment generated by the forest sector is described as highly relevant to forest community well-being under Element 6.3. The latter relationship is reflected in the interaction matrix, while the former would be represented as second-order interactions via Indicators 5.3.1 and 5.3.2.

- 1.3. Are there any overlaps or gaps in the relationship with indicators defined in Eddington and colleague’s (2009) report?

The FFEI project is focused on monitoring key species and ecological processes in order to signal and anticipate the response of forest and rangeland to climate change. There is no inclusion of the socio-economic dimension, so there is no overlap between the C&I framework and the Eddington et al. (2009) report.

2. Independent Climate-Change Assessment

- 2.1. Provide in detail, a qualitative description of what are the expected direct effects of climate change on the indicator, using a broad representation from the literature.

Employment is a major indicator of sustainable economic welfare within a sector of the economy, and it is also used widely to monitor and assess the well-being of rural and forest-based communities (Beckley, 2000; CCFM, 2006; USDA, 2008). Climate change will more than likely affect employment in Canada as the global drive towards a low-carbon economy continues, and may in fact lead to higher employment rates, especially in the long term as new climate-change policy triggers innovation and a restructuring of the global economy (Frankhauser et al., 2008). Climate-change innovation and mitigation policies have frequently been thought to increase employment, especially through investment in energy efficiency (Jochem & Madlener, 2003). Less carbon-intensive markets tend to be more labour intensive and often lead to economic growth and more employment, both in the short and long term (Kammen et al., 2006). There will be loss of jobs in sectors that are directly impacted by climate change, but also new jobs created as replacement industries move in (Frankhauser et al., 2008).

One of the key messages in the climate-change policy literature in terms of employment is that there will be winners and losers. Hopefully, with new innovation and socially sustainable development, the forest sector will be among the winners. With the creation and investment in new and developing forest-based markets, such as bioenergy generation from forest biomass and carbon credit markets, the forest sector may also see some of these predicted benefits to its employment rate (Berndes et al., 2003).

Climate change will likely have the greatest negative implications for employment in the forest sector where impacts on timber supply are most significant in the short term, most often in the form of more severe and frequent natural disturbances (Williamson et al., 2009; Johnston et al., 2010). However, Indicator 5.3.5 is susceptible to the incredibly complex dynamics of the domestic and global economy, and it is difficult to draw a direct connection between climate change and employment rate without many intermediaries.

- 2.2. Given expected changes in Canada's climate, describe if and how the indicator's ability to signal progress towards SFM remains unchanged.

The ability of Indicator 5.3.5 to signal SFM progress will be influenced by climate change.

- 2.3. If an indicator's ability to signal progress towards SFM will be changed, describe if and how the indicator may become worse or better at signalling SFM progress.

The employment rate is a widely accepted indicator of economic welfare and community well-being and resilience. As such, Indicator 5.3.5 will remain an important tool in monitoring SFM progress in relation to the economic and social benefits derived from

forests and SFM under climate change. However, the implications of climate change described above suggest a decline in the predictability of the Indicator. There is also a strong potential for the relevance of Indicator 5.3.5 to increase in light of emerging subsectors like carbon markets and bioenergy. Despite these changes, we believe that employment is a highly understandable and measurable indicator, and Indicator 5.3.5 will not be overly diminished in its ability to signal SFM progress.

3. Integrated Climate-Change Assessment

3.1. What are the key determinants of the indicator (i.e. what causes it to change when it does change);

a) Among other indicators in the C&I framework?

- **The annual harvest of timber products and non-timber forest products are all employment-generating activities, making Indicators 5.3.1 and 5.3.2 determinants of Indicator 5.3.5.**
- **The production timber products is a major driver of employment in the forest sector, making 5.1.3 a determinant of Indicator 5.3.5.**
- **Increases in labour productivity and Indicator 5.3.4 often lead to declines in employment, as they have in the paper manufacturing subsector (CCFM, 2006).**
- **The structure of Crown forest tenures is a highly complex issue, but is no doubt a key determinant of employment in the forest sector.**

b) Among determinants not within the C&I framework?

- **Population growth and decline is a key determinant of employment rates (CCFM, 2006).**
- **New climate-change policies and international agreements can be determinants of innovation and technological development, especially in bioenergy and biotechnology, which are more labour intensive and thus increases employment.**
- **A major shift in the Canadian economy to emergent sectors like information technologies are believed to be detrimental to employment in the forest sector.**

3.2. For what other entities is this indicator a key determinant (i.e. when it changes, what other indicators are influenced to change);

a) Among other indicators in the C&I framework?

- **Indicator 5.3.5 is a key determinant of individual and community well-being in many aspects that are external to the C&I framework, but also largely for rural and resource-dependent communities, as tracked by the indicators within Element 6.3.**
- **Indicator 5.3.5 is also a key determinant of the average income in different employment categories, as tracked by Indicator 5.3.6.**

b) Among determinants not within the C&I framework?

- **Employment, and of course unemployment, is a very important determinant of societal and economic health, the magnitude of which is well outside the scope of this evaluation. Low employment can also be a driver of social and health problems at both the family and community level.**

3.3. To what degree can we now, on the basis of extant knowledge, establish how the key determinants interact cumulatively in influencing the indicator?

Given the multitude of socio-economic determinants of employment rate, and the fact that they interact in unknown or poorly known ways, we are at this time fully unable to specify the cumulative effects of the determinants on employment rate.

3.4. Is the indicator largely unrelated to any other, as described by the linkages assessment and evaluation of key determinants? If so, and the indicator was defined as uninfluenced by climate change in the independent assessment, then it can be placed in category one.

Indicator 5.3.5 is not overly related to other indicators within the C&I framework, but is an important driver of forest-dependent community well-being (Element 6.3). Given the potential for direct, indirect, and induced employment from logging and forestry, wood, and paper subsectors to fluctuate in response to the indirect effects of climate change, we would not deem it uninfluenced or assign it to category one.

3.5. Do the indirect effects of climate change via the linkages with other indicators influence the indicator's ability to signal SFM, regardless of which category was assigned in the independent climate-change assessment?

The indirect influence of climate change on Indicator 5.3.5 can be attributed to two major sources. The first is in relation the climate-change impacts affecting timber supply because of altered disturbance regimes and changes in forest productivity (Williamson et al., 2009), which is influential via Indicators 5.3.1 and 5.1.3. The second is currently external to the C&I framework and has to do with the increasing demand for more efficient and low-emission technologies, many of which can be derived from forest ecosystems (Hall, 2002).

- 3.6. If the indicator's ability to signal SFM progress remains the same under a changing climate, can we conclude no negative influence and leave it unchanged? These indicators can be placed in category two.

The ability of Indicator 5.3.5 to signal SFM progress will remain virtually unchanged despite potential indirect interactions with climate change, and it can therefore be assigned to category two, *Unmodified Indicators*.

- 3.7. If the indicator's ability to signal SFM progress deteriorates when one assumes a changing climate, then what modifications are possible or warranted to improve its ability sufficiently for it to remain among the C&I-SFM? These indicators can be placed in category three.

Not applicable.

- 3.8. If no modifications seem possible or warranted, are we ready to recommend abandonment of the indicator? These indicators can be placed in category four.

Not applicable.

- 3.9. If we recommend abandonment, can we identify any new and closely allied indicators that might suit our needs better under climate change? These indicators can be placed in category five.

Not applicable.

- 3.10. Have extant climate-change impacts made this indicator more pertinent to SFM (i.e. 2.3 and the mountain pine beetle)? These indicators can be placed in category five or considered for conversion from a supporting to a core indicator (where applicable).

Extant effects of climate change on employment are likely. However, they are very difficult to discern due to complexity of the issue, the explosion of divergent public, private, and academic research on this topic, and misinformation due to the politically charged nature of the debate (Martinez-Fernandez et al., 2010). We have definitely seen growth in the labour markets due to the expanding green economy, especially in energy efficiency industries (Frankhauser et al., 2008). Many of these are relevant to the forest sector. However, in the short term it is more likely that the influence of climate change on employment will be negative (Johnston et al., 2010).

The current epidemic of mountain pine beetle (*Dendroctonus ponderosae*) in western Canada is an extant example of how present effects of climate change have influenced employment. The prescribed increase in allowable annual cut in British Columbia in response to the epidemic was done in attempt to salvage some of the beetle infested timber. This consequently led to higher employment rates in the region. However, it is likely that this initial spike in employment due to salvage operations will eventually shift to a decline in employment rates (Parkins & MacKendrick, 2007).

3.11. How should the surviving indicator (the original, modified, or new) be modelled and monitored so that stronger SFM signals may be generated?

The measurability and feasibility of Indicator 5.3.5 will not be altered in any foreseeable manner with respect to climate change. The necessary data to monitor and assess the direct employment rate in the logging and forestry, wood, and paper subsectors are available from the Census of Canada at Statistics Canada. The Statistics Canada Input-Output Model is also used to estimate total direct, indirect, and induced employment from the forest sector (CCFM, 2006). It will also be important to collect data on the growing employment generated from the forest biomass, biomaterials, bioproducts, and carbon subsectors. However, it is more than likely that data availability for this generated employment will be present a challenge for future monitoring endeavours.

3.12. Does this indicator track an entity whose relationship with climate is regionally variable?

The regional variability of climate-change impacts does not diminish the strength of the SFM signal generated by Indicator 5.3.5.

INDICATOR 5.3.6 AVERAGE INCOME IN MAJOR EMPLOYMENT CATEGORIES

1. Linkages Assessment

Table 1.1. Indicators influencing Indicator 5.3.6.

Indicator 5.3.6	Influencing Indicators
First order positive	None
First order negative	None
First order bi-directional	5.2.2, 5.3.5, and 6.3.3

Table 1.2. Indicators influenced by Indicator 5.3.6.

Indicator 5.3.6	Influenced Indicators
First order positive	None
First order negative	None
First order bi-directional	5.2.2 and 6.3.4

- 1.1. Which indicators are influencing and influenced directly (first-order interactions) by the indicator in question? Is the indicator more of a driver of change in other indicators, or being driven by other indicators?

Indicator 5.3.3 is influenced by three other indicators, two of which (Indicators 5.3.5 and 6.3.3) pertain to employment. It influences two other indicators, Indicators 5.2.2 and 6.3.4. Indicator 5.3.6 is relatively equal in its influence on other indicators and the degree to which it is itself influenced.

- 1.2. List the indicators described as ‘relevant indicators under other criteria’ in the 2003 C&I-SFM. Is there any conflict with the interactions described in the matrix?

The economic welfare of the forest sector, including the employment that is generated and the distribution of income in different subsectors is dependent on the condition, productivity, and diversity of forest ecosystems (i.e. Criteria 1 and 2). This is better reflected by the interaction of these indicators with Indicators 5.3.5 and 6.3.3 in the interaction matrix. Employment and income distribution in the forest sector is also described as highly relevant to forest community well-being under Element 6.3.

- 1.3. Are there any overlaps or gaps in the relationship with indicators defined in Eddington and colleague’s (2009) report?

The FFEI project is focused on monitoring key species and ecological processes in order to signal and anticipate the response of forest and rangeland to climate change. There is no inclusion of the socio-economic dimension, so there is no overlap between the C&I framework and the Eddington et al. (2009) report.

2. Independent Climate-Change Assessment

- 2.1. Provide in detail, a qualitative description of what are the expected direct effects of climate change on the indicator, using a broad representation from the literature.

Several studies have explored the implications of climate change for future forest product markets (Perez-Garcia et al., 2002; Kirilenko & Sedjo, 2007; Jonsson, 2009). It is anticipated that the global increase in the supply of wood fibre caused by climate warming will generate a decline in prices and lead to an overall increase in consumption of forest products and economic welfare of the global forest sector (Sohngen & Mendelsohn, 1998; Irland et al., 2001; Perez-Garcia et al., 2002). However, in Canada the relatively high cost of production for forest products will lead to a decline in national harvest rates and a negative influence of climate change for the economic welfare of the forest sector (Perez-Garcia et al., 2002). Although these predictions are highly uncertain, as is the response of average incomes in various forest product manufacturing industries, we might expect to see some fluctuations in Indicator 5.3.6. Moreover, the increase in frequency and severity of natural disturbance events in forest ecosystems may have negative implications for the supply of wood fibre for manufacturing (Johnston et al., 2010).

Indicator 5.3.6 is closely linked to employment in the forest sector, as tracked by Indicators 5.3.5 and 6.3.3. As such, employment increases resulting from growth in bioenergy industries and in carbon markets (Berndes et al., 2003; Freedman et al., 2009) might have implications for the predictability of average incomes in the forest sector and their relevance to SFM. However these anticipated issues are far more pertinent to the aforementioned indicators of forest-sector employment.

- 2.2. Given expected changes in Canada's climate, describe if and how the indicator's ability to signal progress towards SFM remains unchanged.

The potential influence of climate change on the average income in the wood, logging, and paper subsectors is removed by several intermediary linkages with other indicators. Despite some decline in the predictability of the Indicator, we strongly suspect that there will be no discernable effects of climate change on the ability of Indicator 5.3.6 to signal our progress towards SFM.

- 2.3. If an indicator's ability to signal progress towards SFM will be changed, describe if and how the indicator may become worse or better at signalling SFM progress.

The ability of Indicator 5.3.6 to signal SFM progress will not be diminished by climate change.

3. Integrated Climate-Change Assessment

3.1. What are the key determinants of the indicator (i.e. what causes it to change when it does change);

a) Among other indicators in the C&I framework?

- **Indicators 5.3.5 and 6.3.3 are very closely related to the average income in major employment categories of the forest sector and are key determinants of Indicator 5.3.6.**
- **Indicator 5.3.6 is also linked to the distribution of financial of benefits in the timber products sector and is therefore determined by Indicator 5.2.2.**

b) Among determinants not within the C&I framework?

- **The skill and level of training of personnel in different forest subsectors, as well as different company policies, are determinants of Indicator 5.3.6.**
- **The average income in other manufacturing sectors of the Canadian economy will be influential on Indicator 5.3.5. The Indicator relates incomes within the forest sector to all other manufacturing.**

3.2. For what other entities is this indicator a key determinant (i.e. when it changes, what other indicators are influenced to change);

a) Among other indicators in the C&I framework?

- **The incidence of low income in forest-based communities is determined in part by Indicator 5.3.6.**
- **Indicator 5.3.6 also is a determinant of the distribution of incomes in the forest sector and of Indicator 5.2.2.**

b) Among determinants not within the C&I framework?

- **Indicator 5.3.6 is a determinant of social well-being and the equitable distribution of wealth within the forest sector in relation to other manufacturing sectors.**

3.3. To what degree can we now, on the basis of extant knowledge, establish how the key determinants interact cumulatively in influencing the indicator?

Average income in major employment categories is influenced by many determinants that are abstract and difficult to quantify, so our comprehension of how they interact to influence Indicator 5.3.6 is relatively low. However, we know that it is tightly linked with employment and Indicator 5.3.5 (CCFM, 2006).

- 3.4. Is the indicator largely unrelated to any other, as described by the linkages assessment and evaluation of key determinants? If so, and the indicator was defined as uninfluenced by climate change in the independent assessment, then it can be placed in category one.

Indicator 5.3.6 is largely unrelated to other indicators within the C&I framework, though it is linked to many different facets of society and community well-being. Given the unlikely and weak influence of climate change on this Indicator, we recommend assigning it to category one, *Uninfluenced Indicators*.

- 3.5. Do the indirect effects of climate change via the linkages with other indicators influence the indicator's ability to signal SFM, regardless of which category was assigned in the independent climate-change assessment?

If there will be any climate-change influence on the distribution of income in major forest-sector employment categories, it will likely occur as a result in both increases and decreases in the supply of timber due to changes in forest productivity and natural disturbance regimes, respectively (Johnston et al., 2010). However, these impacts have far more relevance to Indicators 5.3.1 and 5.1.3.

- 3.6. If the indicator's ability to signal SFM progress remains the same under a changing climate, can we conclude no negative influence and leave it unchanged? These indicators can be placed in category two.

Not applicable. The Indicator's ability is uninfluenced and has been assigned to category one.

- 3.7. If the indicator's ability to signal SFM progress deteriorates when one assumes a changing climate, then what modifications are possible or warranted to improve its ability sufficiently for it to remain among the C&I-SFM? These indicators can be placed in category three.

Not applicable.

- 3.8. If no modifications seem possible or warranted, are we ready to recommend abandonment of the indicator? These indicators can be placed in category four.

Not applicable.

- 3.9. If we recommend abandonment, can we identify any new and closely allied indicators that might suit our needs better under climate change? These indicators can be placed in category five.

Not applicable.

- 3.10. Have extant climate-change impacts made this indicator more pertinent to SFM (i.e. 2.3 and the mountain pine beetle)? These indicators can be placed in category five or considered for conversion from a supporting to a core indicator (where applicable).

There are no pertinent examples of climate-change impacts that have influenced the distribution of income across different employment categories in the forest sector.

- 3.11. How should the surviving indicator (the original, modified, or new) be modelled and monitored so that stronger SFM signals may be generated?

Real average income data for the logging, wood, and paper subsectors used in the measurement of Indicator 5.3.6 were collected from Statistics Canada in the 2005 C&I-SFM assessment (Statistics Canada, 2004; CCFM, 2006). This will more than likely remain a viable approach for the monitoring of the Indicator under climate change.

- 3.12. Does this indicator track an entity whose relationship with climate is regionally variable?

The regional variability of climate-change impacts does not diminish the strength of the SFM signal generated by Indicator 5.3.6.

**INDICATOR 6.1.1 EXTENT OF CONSULTATION WITH
ABORIGINALS IN FOREST MANAGEMENT PLANNING AND IN THE
DEVELOPMENT OF POLICIES AND LEGISLATION RELATED TO
FOREST MANAGEMENT,**

**INDICATOR 6.1.2 AREA OF FOREST LAND OWNED BY ABORIGINAL
PEOPLES, AND**

**INDICATOR 6.2.1 AREA OF FORESTED CROWN LAND WITH
TRADITIONAL LAND USE STUDIES**

1. Linkages Assessment

Table 1.1. Indicators influencing Indicators 6.1.1, 6.1.2, and 6.2.1.

Indicator 6.1.1	Influencing Indicators
First order positive	None
First order negative	None
First order bi-directional	None
Indicator 6.1.2	
First order positive	2.2
First order negative	None
First order bi-directional	None
Indicator 6.2.1	
First order positive	6.5.3
First order negative	None
First order bi-directional	None

Table 1.2. Indicators influenced by Indicators 6.1.1, 6.1.2, and 6.2.1.

Indicator 6.1.1	Influencing Indicators
First order positive	None
First order negative	None
First order bi-directional	None
Indicator 6.1.2	
First order positive	None
First order negative	None
First order bi-directional	5.2.1
Indicator 6.2.1	
First order positive	None
First order negative	None
First order bi-directional	None

- 1.1. Which indicators are influencing and influenced directly (first-order interactions) by the indicator in question? Is the indicator more of a driver of change in other indicators, or being driven by other indicators?

Indicators 6.1.1, 6.1.2, and 6.2.1 are largely unrelated to other indicators in the C&I framework, with a total three first-order interactions for all three Indicators. Indicator 6.1.1 has no direct interactions with any other indicators. Indicator 6.1.2 is influenced by Indicator 2.2 and influences Indicator 5.2.1. Finally, Indicator 6.2.1 is influenced by Indicator 6.5.3. None of these three indicators are major drivers of change, nor are they significantly driven to change by other indicators.

- 1.2. List the indicators described as ‘relevant indicators under other criteria’ in the 2003 C&I-SFM. Is there any conflict with the interactions described in the matrix?

No relevant relationships between Indicators 6.1.1, 6.1.2, and 6.2.1 with other indicators in the C&I framework are described in the 2003 C&I-SFM report.

- 1.3. Are there any overlaps or gaps in the relationship with indicators defined in Eddington and colleague’s (2009) report?

The FFEI project is focused on monitoring key species and ecological processes in order to signal and anticipate the response of forest and rangeland to climate change. There is no inclusion of the socio-economic dimension of SFM, so there is no overlap between the C&I framework and the Eddington et al. (2009) report.

2. Independent Climate-Change Assessment

- 2.1. Provide in detail, a qualitative description of what are the expected direct effects of climate change on the indicator, using a broad representation from the literature.

Many Aboriginal populations are considered highly vulnerable to global environmental change because of the close relationship they have with the natural environment (Ford & Smit, 2004; Furgal & Seguin, 2006). Furthermore, they are often socially marginalized or impoverished, which contributes to their vulnerability (Kovats et al., 2003). One primary concern is the health implications for Aboriginal populations under climate change, which might include heat-stress from the warming temperatures, failures of inadequate infrastructure, a decline in food and water security, and mental-health impacts arising from the declining feasibility of traditional lifestyles and from community relocation (Furgal & Seguin, 2006).

A key focus in the research on Aboriginal vulnerability to climate change is on northern populations, where the change in climate is predicted to be most severe and where cold-adapted ecosystems are highly sensitive to changes in climate (IPCC, 2007; Ford & Smit, 2004; Juday et al., 2005; Furgal & Seguin, 2006). Forest-sector activity in the Yukon and Northwest Territories is relatively sparse, but the harvest of timber and non-timber forest products and forest-based services are still an important source of revenue for northern communities (Rothman & Herbert, 1997; CCFM, 2006). Canada’s northern forests are

also culturally and spiritually important to Aboriginal peoples and many of their traditional land-uses and lifestyles (Cohen, 1997). Many of these traditional land-uses are centred on non-timber forest products and forest-based services (Duchesne & Wetzel, 2002; Nuttall et al., 2005). Climate change threatens the ecosystem, species, and genetic diversity of forest ecosystems and subsequently will have major implications for the supply of these forest ecosystem goods and services (Cohen, 1997; Gray, 2005; Johnston et al., 2010).

There are several extent and predicted climate-change impacts on forest ecosystems and their provision of ecosystem goods and services. Changes in population dynamics and the distribution of woodland caribou (*Rangifer tarandus caribou*) in response to the melting of the permafrost, habitat change, and decline in browse availability are highly likely to result from climate change (Tyler, 2010; Vitt et al., 2010). This will adversely affect many northern Aboriginal populations that are highly dependent on caribou as a source of food and income (Nuttall et al., 2005). The increased severity and frequency of insect outbreaks and wildfires (Dale et al., 2001) in general have negative implications for the ability of Aboriginals to practice traditional lifestyles (Furgal & Seguin, 2006). However, there are instances where some NTFP and associated activities may benefit from the changes in climate, such as the supply of morel (*Morchella* spp.) mushrooms that thrive in areas recently burned by wildfire (Williamson et al., 2009). A key vulnerability of Aboriginal peoples that rely on traditional land-uses is the fact that different cultural groups and communities are specifically adapted to their regional ecology, which may no longer be static in the coming decades (Furgal & Seguin, 2006).

There is far less attention in the literature to the vulnerability of Aboriginal populations and First Nations outside of northern Canada. However, these same vulnerabilities threaten traditional lifestyles throughout the Country. These discussed implications for Indicator 6.2.1 may increase the relevance and need for studies on traditional land-uses in forest ecosystems, but are not nearly as relevant to the physical area of forested Crown land where such studies occur.

Concurrent to the threat from climate change to traditional land-use activities are prospective changes to the area of forested land owned by Aboriginal peoples under climate change. This is not due to a change in the area of land owned, but rather the shifting climatic ranges of tree species (McKenney et al., 2007). In the northern boreal-tundra ecotone, the treeline is limited by temperature and is sensitive to climate-warming. The migration of tree species and subsequent treeline advancement (Danby & Hik, 2007) may incidentally change the area of forest that is owned by Aboriginal peoples. The extent of consultation with Aboriginals in forest management planning and in the development of forest management policies and legislation (Indicator 6.1.1) has no discernable relationship with climate change.

Monitoring and assessing natural-resource issues pertaining to Canada's Aboriginal populations are essential to SFM. However, this presents a significant challenge at the national scale because of the diversity of the Aboriginal population in Canada and between jurisdictions, and the uniqueness of the issues that face them, often at the community level.

A general feeling among Aboriginal populations in past C&I initiatives is that the assessment of their values and objectives were curtailed (Adam & Kneeshaw, 2009). Recent research by the Sustainable Forest Management Network suggests that local, bottom-up approaches to C&I monitoring may be the best approach to fully represent Aboriginal values and objectives in SFM (Karjala et al., 2004; Kopra & Stevenson, 2008; Adam & Kneeshaw, 2009).

- 2.2. Given expected changes in Canada's climate, describe if and how the indicator's ability to signal progress towards SFM remains unchanged.

Indicator 6.1.1 is a socioeconomic action indicator, and is therefore relatively free from climate-change influence. Involving Aboriginal peoples and accommodating their interests in natural resource planning and development will certainly remain a government priority in the future and a fundamental component of SFM, and will likely become increasingly important in regions with high climate-change vulnerability. However, climate change has no influence over the extent of consultation with Aboriginal peoples in forest management planning and the development of policies and legislation by jurisdictional governments, as tracked by Indicator 6.1.1.

Indicators 6.1.2 and 6.2.1 are also socioeconomic action indicators, but do suffer some decline in their predictability. The temperature-induced advancement of treelines into the tundra and arctic ecozones may incidentally increase the amount of forested land owned by Aboriginal peoples. Moreover, these ecological effects of climate change may threaten some traditional land-uses and subsequently generate more research and land-use studies on Crown land. Despite these declines in indicator predictability, other indicator traits remain uninfluenced and there will be no significant decline in the SFM signals generated by Indicators 6.1.2 and 6.2.1.

- 2.3. If an indicator's ability to signal progress towards SFM will be changed, describe if and how the indicator may become worse or better at signalling SFM progress.

There will be no significant decline in the ability of Indicators 6.1.1, 6.1.2, and 6.1.3 to signal our progress towards SFM.

3. Integrated Climate-Change Assessment

- 3.1. What are the key determinants of the indicator (i.e. what causes it to change when it does change);

- a) Among other indicators in the C&I framework?
- **The investment into forest research and education (Indicator 6.5.3) is a driver of Indicator 6.2.1.**

- **Major changes in land-use resulting from permanent deforestation or afforestation may influence the forested land owned by Aboriginal peoples, making Indicator 2.2 a determinant of Indicator 6.1.2.**

b) Among determinants not within the C&I framework?

- **Jurisdictional and corporate policies, new legislation development, and established Aboriginal and treaty rights under the Canadian Constitution are all determinants of Indicator 6.1.1 and 6.1.2.**
- **First Nations land claims, treaty land entitlements, and band purchases are key determinants of Indicator 6.1.2 (CCFM, 2006).**
- **The funding and trends of academic research, such as recent major efforts like the third International Polar Year in 2007-2009, are determinants of Indicator 6.2.1.**

3.2. For what other entities is this indicator a key determinant (i.e. when it changes, what other indicators are influenced to change);

a) Among other indicators in the C&I framework?

- **The area of forested land owned by Aboriginal peoples may further influence the type and extent of timber tenures, making Indicator 6.1.2 a determinant of Indicator 5.2.1.**

b) Among determinants not within the C&I framework?

- **Indicators 6.1.1 and 6.1.2 can be influential on the total participation of Aboriginal peoples in forest management activities in Canada.**
- **Aboriginal involvement in studies on traditional land-uses can influence community pride in cultural history and awareness of traditional ecological knowledge, as well as provide important information on culturally important areas for conservation.**
- **Traditional ecological knowledge of Aboriginal land-use practices is becoming increasingly recognized as a valuable input into contemporary or 'western' science and environmental management.**

3.3. To what degree can we now, on the basis of extant knowledge, establish how the key determinants interact cumulatively in influencing the indicator?

Our ability to fully grasp the cumulative influence of these determinants on the level of respect for Aboriginal and treaty rights and traditional land-uses and ecological knowledge is severely limited. This is emphasised by the fact that these three Indicators, though critical to SFM progress, are largely unrelated to other indicators in the C&I framework.

- 3.4. Is the indicator largely unrelated to any other, as described by the linkages assessment and evaluation of key determinants? If so, and the indicator was defined as uninfluenced by climate change in the independent assessment, then it can be placed in category one.

Indicator 6.1.1 is entirely unrelated to other indicators and is free of climate-change influence, as many other action indicators are. We recommend assigning it to category one, *Uninfluenced Indicators*. Because of the implications of climate change for the predictability of Indicators 6.1.2 and 6.2.1, and possibly for the relevance of Indicator 6.2.1, we do not recommend assigning them to category one.

- 3.5. Do the indirect effects of climate change via the linkages with other indicators influence the indicator's ability to signal SFM, regardless of which category was assigned in the independent climate-change assessment?

The core cause of climate-change influence on Indicators 6.1.2 and 6.2.1 are the impacts on biological diversity and forest ecosystem condition and productivity (Criteria 1 and 2), as is the case for most socioeconomic indicators. A key relationship under climate change may also be the interactions between Criteria 1 and 2, Indicator 5.3.2, and Indicators 6.1.2 and 6.2.1. The migration of the treeline in the boreal-tundra ecotone, as would be tracked by Indicator 2.2, is also relevant to Indicator 6.1.2.

- 3.6. If the indicator's ability to signal SFM progress remains the same under a changing climate, can we conclude no negative influence and leave it unchanged? These indicators can be placed in category two.

The ability of Indicators 6.1.2 and 6.2.1 to signal SFM progress will not be overly diminished despite the described implications of climate change for Aboriginal populations and northern communities. In fact, Indicator 6.2.1 may increase in relevance if climate change affects the ability to maintain Aboriginal traditional activities on forested land. However, this does not decrease the strength of the Indicator, and we recommend assigning both Indicators to category two, *Unmodified Indicators*.

- 3.7. If the indicator's ability to signal SFM progress deteriorates when one assumes a changing climate, then what modifications are possible or warranted to improve its ability sufficiently for it to remain among the C&I-SFM? These indicators can be placed in category three.

Not applicable.

- 3.8. If no modifications seem possible or warranted, are we ready to recommend abandonment of the indicator? These indicators can be placed in category four.

Not applicable.

- 3.9. If we recommend abandonment, can we identify any new and closely allied indicators that might suit our needs better under climate change? Are there any other reasons for the creation of an additional indicator? These indicators can be placed in category five.

Not applicable.

- 3.10. Have extant climate-change impacts made this indicator more pertinent to SFM (i.e. 2.3 and the mountain pine beetle)? These indicators can be placed in category five or considered for conversion from a supporting to a core indicator (where applicable).

Treeline advance and increases in the density of white spruce (*Picea glauca*) and willow (*Salix* spp.) in subarctic ecotones has already been observed in the Yukon, which have been attributed to the recent climate warming (Danby & Hik, 2007). Moreover, the Yukon's Kluane National Park and Reserve experienced extremely severe outbreaks of spruce beetle (*Dendroctonus rufipennis*), which have also been attributed to recent high summer temperatures (Berg et al., 2009). Both of these impacts are highly pertinent to northern Aboriginal populations and subsistence land-uses.

- 3.11. How should the surviving indicator (the original, modified, or new) be modelled and monitored so that stronger SFM signals may be generated?

The monitoring and assessment of Indicators 6.1.1, 6.1.2, and 6.2.1 all suffer from a lack of available data, and often from the Aboriginal desire not to share some traditional knowledge with the public domain (CCFM, 2006). These are obviously representative of major challenges to the measurability and feasibility of these Indicators. However, the changing climate will not exacerbate these existing challenges to the Indicators' abilities in signalling SFM progress.

- 3.12. Does this indicator track an entity whose relationship with climate is regionally variable?

There are potential regional implications of climate change for Indicators 6.1.2 and 6.2.1, but not for Indicator 6.1.1, especially amongst northern populations.

INDICATOR 6.3.1 ECONOMIC DIVERSITY INDEX OF FOREST-BASED COMMUNITIES,

INDICATOR 6.3.2 EDUCATION ATTAINMENT LEVELS IN FOREST-BASED COMMUNITIES,

INDICATOR 6.3.3 EMPLOYMENT RATE IN FOREST-BASED COMMUNITIES, AND

INDICATOR 6.3.4 INCIDENCE OF LOW INCOME IN FOREST-BASED COMMUNITIES

1. Linkages Assessment

Table 1.1. Indicators influencing Indicators 6.3.1, 6.3.2, 6.3.3, and 6.3.4.

Indicator 6.3.1	Influencing Indicators
First order positive	5.3.2 and 6.3.2
First order negative	None
First order bi-directional	5.3.1 and 5.3.5
Indicator 6.3.2	
First order positive	6.5.3
First order negative	None
First order bi-directional	None
Indicator 6.3.3	
First order positive	5.1.3, 5.3.1, 5.3.2, 5.3.5, 6.3.1, and 6.3.2
First order negative	5.3.4
First order bi-directional	5.2.1
Indicator 6.3.4	
First order positive	None
First order negative	5.3.5, 6.3.1, 6.3.2, and 6.3.3
First order bi-directional	5.2.2 and 5.3.6

Table 1.2. Indicators influenced by Indicators 6.3.1, 6.3.2, 6.3.3, and 6.3.4.

Indicator 6.3.1	Influencing Indicators
First order positive	5.3.5 and 6.3.3
First order negative	6.3.4
First order bi-directional	None
Indicator 6.3.2	
First order positive	5.3.4, 6.3.1, and 6.3.3
First order negative	6.3.4
First order bi-directional	None
Indicator 6.3.3	
First order positive	None
First order negative	6.3.4
First order bi-directional	5.2.2 and 5.3.6
Indicator 6.3.4	
First order positive	None

Indicator 6.3.1	Influencing Indicators
First order negative	None
First order bi-directional	None

- 1.1. Which indicators are influencing and influenced directly (first-order interactions) by the indicator in question? Is the indicator more of a driver of change in other indicators, or being driven by other indicators?

Indicator 6.3.1 is influenced by four other indicators, and influences three. Indicator 6.3.3 is influenced by eight indicators, and influences three others. Indicator 6.3.4 is influenced by six other indicators and does not influence any other. All of these first-order interactions are between indicators in Criteria 5 and 6, and most of those within Element 5.3. Indicators 6.3.1, 6.3.3, and 6.3.4 are socioeconomic state indicators and are much more driven to change by other indicators than drivers of change. Indicator 6.3.2 is influenced by only one Indicator, 6.5.3, and influences four others. It is more of a driver of change than it is influenced by other indicators.

- 1.2. List the indicators described as ‘relevant indicators under other criteria’ in the 2003 C&I-SFM. Is there any conflict with the interactions described in the matrix?

The well-being and resilience of forest-based communities are described as relevant to Element 5.3, especially to Indicators 5.3.1 and 5.3.2. of course, the other indicators related to employment, including Indicators 5.3.5 and 5.3.6 are considered relevant. Finally, the structure and extent of Crown forest tenures, tracked by Indicator 5.2.1, has connotations for employment and overall community stability. These are all indicators described as influential in the interaction matrix.

- 1.3. Are there any overlaps or gaps in the relationship with indicators defined in Eddington and colleague’s (2009) report?

The FFEI project is focused on monitoring key species and ecological processes in order to signal and anticipate the response of forest and rangeland to climate change. There is no inclusion of the socio-economic dimension, so there is no overlap between the C&I framework and the Eddington et al. (2009) report.

2. Independent Climate-Change Assessment

- 2.1. Provide in detail, a qualitative description of what are the expected direct effects of climate change on the indicator, using a broad representation from the literature.

The dynamics of resource-dependent communities in Canada are incredibly complex, though relatively well studied, including several criteria-and-indicator-based initiatives (Beckley, 2000; Beckley et al., 2002; Natcher & Hickey, 2002; Medis et al., 2003; Karjala et

al., 2004). It is now widely recognized that resource-dependent Aboriginal and non-Aboriginal communities in Canada, particularly forest-based communities, are potentially vulnerable to the changing climate (Davidson et al., 2003; Parkins & MacKendrick, 2007; Williamson et al., 2008; Williamson & Watson, 2010). This is not only because many of these communities are in climatically sensitive regions, like northern Canada, and in close proximity to forest ecosystems, but because of their unique social and political structure (Davidson et al., 2003). In addition to the impacts of climate change on human health and infrastructure that will be experienced across Canada, forest-based communities will be faced with additional risks because of their reliance on forest ecosystems (Williamson et al., 2008).

Perceived vulnerability and risk in these forest-dependent communities are also critical to community well-being and the assignment of risks of climate change, as it incorporates a broader range of values and complexities that can be overlooked by more narrow, technical risk assessments (Slovic, 1997). A survey of rural populations in central British Columbia found that citizens perceived climate change as a considerable threat to natural capital and the flow of ecosystem goods and services (Williamson & Watson, 2010).

Ecological and economic impacts of climate change in forest-dependent communities are attributed mainly to catastrophic disturbance events within the short term (Johnston et al., 2010). While this is indeed highly likely, social vulnerability and adaptive capacity to climate change, including forest community well-being, will also be highly susceptible to widespread environmental change over the longer term (Parkins & MacKendrick, 2007). These short-term impacts of climate change are often predicted to cause an economic boom in the forest sector due to the increase of salvage operations and allowable annual cuts, as it has in response to the mountain pine beetle (*Dendroctonus ponderosae*) in western Canada (Pederson, 2004; Williamson et al., 2008). This will likely be followed by regional declines or collapses of the timber supply (British Columbia Ministry of Forests and Range, 2007). Over the longer term, more gradual, temperature-induced increases in forest productivity may also prove influential and potentially beneficial for forest-dependent communities.

A critical issue for future monitoring efforts of forest community well-being and resilience is the regional specificity of each forest-based community, and the uniqueness of the challenges facing them. Local analyses will be necessary to address the vulnerability and adaptive capacity of forest-based communities to climate change (Williamson et al., 2008; Adam & Kneeshaw, 2009).

2.2. Given expected changes in Canada's climate, describe if and how the indicator's ability to signal progress towards SFM remains unchanged.

Indicators 6.3.1, 6.3.3, and 6.3.4 are all influenced by climate change in a near identical fashion. The short- and long-term ecological, economic, and social, impacts of climate change will reduce the predictability of these three socioeconomic condition/response Indicators. These three Indicators are well established measures of community well-being and resilience (Beckley, 2000). It is more than likely that these will remain a vital tool in

monitoring SFM progress in relation to society's responsibility in managing the economic and social benefits of forests in Canada as the climate changes. The vulnerability of forest-based communities to climate change is not only wrought with uncertainty, but the differing issues that will arise based on the geographic location of these communities and region-specific impacts prevents any additional measures in future C&I-SFM monitoring initiatives at the national scale.

Indicator 6.3.2 is the only indicator within Element 6.3 that will be entirely uninfluenced by climate change in its ability to signal SFM progress, as it tracks a climatically insensitive phenomenon.

2.3. If an indicator's ability to signal progress towards SFM will be changed, describe if and how the indicator may become worse or better at signalling SFM progress.

Indicator 6.3.2 will not deteriorate under climate change. Indicators 6.3.1, 6.3.3, and 6.3.4 will suffer a decline in their predictability, but not to the level that their SFM signals no longer have value to the C&I-SFM.

3. Integrated Climate-Change Assessment

3.1. What are the key determinants of the indicator (i.e. what causes it to change when it does change);

- a) Among other indicators in the C&I framework?
 - **The harvest and production timber and non-timber forest products are drivers of forest community well-being, making Indicators 5.1.3, 5.3.1, and 5.3.2 determinants of almost all indicators within Element 6.3.**
 - **Indicator 6.3.1 is a determinant of employment in forest-dependent communities. However, one of the key drivers of economic diversity is thought to be indirect and induced employment from the forest sector, which also makes Indicator 5.3.5 a determinant of Indicator 6.3.1.**
 - **Investment in education, as tracked by Indicator 6.5.3, is a vital determinant of Indicator 6.3.2.**
 - **A key determinant of Indicators 6.3.3 and 6.3.4 is employment in the forest sector, tracked by Indicator 5.3.5.**
 - **Economic diversity, tracked by Indicator 6.3.1, is a determinant of Indicators 6.3.3 and 6.3.4, as more diverse employment opportunities tend to generate more employment (Beckley, 2000).**

- **The incidence of low employment, tracked by Indicator 6.3.4, is highly determined by the distribution of income and financial benefits within the forest sector, as tracked by Indicators 5.2.2 and 5.3.6.**
- **Indicator 6.3.4 is also determined by all other indicators of forest community well-being and resilience within Element 6.3.**

b) Among determinants not within the C&I framework?

- **Economic diversity and education are variable between Aboriginal and non-Aboriginal resource-dependent communities in Canada's census subdivisions, though this is also influenced by subdivision size, as larger subdivisions tend to have higher economic diversity (CCFM, 2006).**
- **Population growth and decline in forest-dependent and rural communities, especially the widespread migration of rural citizens to urban areas, are key determinants of community well-being and Element 6.3.**
- **Community size and family size are important determinants of what is considered low income and poverty.**

3.2. For what other entities is this indicator a key determinant (i.e. when it changes, what other indicators are influenced to change);

a) Among other indicators in the C&I framework?

- **Employment opportunities, which are tracked by Indicators 5.3.5 and 6.3.3, benefit from economic diversity and thus are in-part determined by Indicator 6.3.1.**
- **Education attainment is a key determinant of forest-dependent community well-being and resilience, making it a determinant of Indicators 6.3.1, 6.3.3, and 6.3.4.**
- **The skill of labour, and therefore labour productivity and growth tracked by Indicator 5.3.4, is in-part determined by education levels and Indicator 6.3.2.**
- **Indicator 6.3.3, along with Indicator 5.3.5, is an important determinant of the equal distribution of wealth, tracked by Indicators 5.2.2, 5.3.6, and 6.3.4.**

b) Among determinants not within the C&I framework?

- **Communities with high economic diversity, as tracked by Indicator 6.3.1, are often more resilient to major economic shocks and recessions (CCFM, 2006).**

- **Education levels are an important determinant of overall human capital in forest-dependent communities.**
- **Employment and the frequency of low income and poverty are very important determinants of societal and economic health, the magnitude of which is well outside the scope of this evaluation. One key importance of employment in forest-based communities is that low employment and income can be a driver of social and health problems at both the family and community level.**
- **The incidence of low income in forest-dependent communities is an important measure of poverty in these areas.**

3.3. To what degree can we now, on the basis of extant knowledge, establish how the key determinants interact cumulatively in influencing the indicator?

Given the multitude of socio-economic determinants influencing forest-based communities, and the fact that they interact in unknown or poorly known ways, we are at this time fully unable to specify the cumulative effects of the determinants on these four Indicators.

3.4. Is the indicator largely unrelated to any other, as described by the linkages assessment and evaluation of key determinants? If so, and the indicator was defined as uninfluenced by climate change in the independent assessment, then it can be placed in category one.

Indicators in Element 6.3 range from moderately related to other socioeconomic indicators, primarily from Criterion 5, to largely unrelated. Indicator 6.3.2 primarily influences the other indicators of forest community well-being and resilience, and is entirely unaffected by climate change. We therefore recommend assigning Indicator 6.3.2 to category one, *Uninfluenced Indicators*.

3.5. Do the indirect effects of climate change via the linkages with other indicators influence the indicator's ability to signal SFM, regardless of which category was assigned in the independent climate-change assessment?

The vulnerability of forest-based communities is a complex matter, with a wide array of implications in the short and long term. This vulnerability is largely because of an unstable and unpredictable future timber supply. Therefore, the most important interaction of these four Indicators will be with Indicator 5.3.1, as it will track fluctuations in timber supply in response to the changing climate.

3.6. If the indicator's ability to signal SFM progress remains the same under a changing climate, can we conclude no negative influence and leave it unchanged? These indicators can be placed in category two.

Indicators 6.3.1, 6.3.3, and 6.3.4 will likely sustain a decline only in their predictability and will not sustain a significant decline in their ability to signal SFM progress. We also cannot identify any modifications that would abate this decline. Therefore, these Indicators can remain unmodified and be placed in category two, *Unmodified Indicators*.

- 3.7. If the indicator's ability to signal SFM progress deteriorates when one assumes a changing climate, then what modifications are possible or warranted to improve its ability sufficiently for it to remain among the C&I-SFM? These indicators can be placed in category three.

Not applicable. There are no possible modifications to these four established Indicators of forest community well-being and resilience that we can see that would address the introduced vulnerability of climate change in these communities.

- 3.8. If no modifications seem possible or warranted, are we ready to recommend abandonment of the indicator? These indicators can be placed in category four.

Not applicable. We do not recommend abandonment of any indicators within Element 6.3.

- 3.9. If we recommend abandonment, can we identify any new and closely allied indicators that might suit our needs better under climate change? These indicators can be placed in category five.

Not applicable. There are no conceivable indicators to further address the vulnerability of forest-based communities at the national scale.

- 3.10. Have extant climate-change impacts made this indicator more pertinent to SFM (i.e. 2.3 and the mountain pine beetle)? These indicators can be placed in category five or considered for conversion from a supporting to a core indicator (where applicable).

The case study Vanderhoof, British Columbia by Williamson and colleagues (2008) is an excellent example of the complex interactions of climate change with communities that rely heavily on forest resources. The driver behind the socioeconomic implications of climate change in Vanderhoof is of course the ongoing outbreak of mountain pine beetle (*Dendroctonus ponderosae*) in central British Columbia. Widespread infestation and mortality in the region's vast forests of mature lodgepole pine (*Pinus cordata*) have resulted in an increase in allowable annual cut in the Prince George Timber Supply Area where the community is located in order to salvage some of the beetle-killed pine. As of 2007, the Vanderhoof economy had been considerably strengthened by this increase in available timber. However, this is of course not a sustainable economic boom, and socioeconomic

conditions of the community will most likely worsen when the supply of available beetle-infested timber is exhausted or beyond salvage.

3.11. How should the surviving indicator (the original, modified, or new) be modelled and monitored so that stronger SFM signals may be generated?

The necessary data to monitor and assess these Indicators of forest-based community well-being and resilience in Canada can be readily obtained from the Census of Canada at Statistics Canada. However, because of the unique set of issues in each region and indeed in each community across Canada, future monitoring of these Indicators could be augmented by specific case studies, such as the Beckley (2000) and Williamson et al. (2008) reports.

3.12. Does this indicator track an entity whose relationship with climate is regionally variable?

The different geography and locality of different forest-based communities in Canada will make these four Indicators regionally sensitive to climate change.

INDICATOR 6.4.1 PROPORTION OF PARTICIPANTS WHO ARE SATISFIED WITH PUBLIC INVOLVEMENT PROCESSES IN FOREST MANAGEMENT IN CANADA

1. Linkages Assessment

Table 1.1. Indicators influencing Indicator 6.4.1.

Indicator 6.4.1	Influencing Indicators
First order positive	None
First order negative	None
First order bi-directional	5.2.1

Table 1.2. Indicators influenced by Indicator 6.4.1.

Indicator 6.4.1	Influenced Indicators
First order positive	None
First order negative	None
First order bi-directional	None

- 1.1. Which indicators are influencing and influenced directly (first-order interactions) by the indicator in question? Is the indicator more of a driver of change in other indicators, or being driven by other indicators?

Indicator 6.4.1 is only influenced by one other indicator, Indicator 5.2.1, and has no direct influence over any others within the C&I framework. It is essentially unrelated to other indicators, though as a socioeconomic state indicator, it is more driven to change by other indicators than a driver of change in them.

- 1.2. List the indicators described as ‘relevant indicators under other criteria’ in the 2003 C&I-SFM. Is there any conflict with the interactions described in the matrix?

No other indicators are described as relevant to Indicator 6.4.1 or to fair and effective decision-making within the 2003 C&I-SFM report.

- 1.3. Are there any overlaps or gaps in the relationship with indicators defined in Eddington and colleague’s (2009) report?

The FFEI project is focused on monitoring key species and ecological processes in order to signal and anticipate the response of forest and rangeland to climate change. There is no inclusion of the socio-economic dimension, so there is no overlap between the C&I framework and the Eddington et al. (2009) report.

2. Independent Climate-Change Assessment

- 2.1. Provide in detail, a qualitative description of what are the expected direct effects of climate change on the indicator, using a broad representation from the literature.

Forest management in Canada has shifted from a fairly closed institution to a more inclusive and engaging process (Duinker, 1998). Public participation is now a widely used tool to address the broader social, economic, and ecological values in forest management planning which have developed over the past two decades (McGurk et al., 2006; Martineau-Delisle & Nadeau, 2010). Local citizen advisory committees are one of the primary methods in which provincial governments and forest companies both address public participation laws and policies and utilize public participation in their forest management planning (CCFM, 2006; McGurk et al., 2006). Surveys of the level of satisfaction with these advisory committee processes was the approach to monitoring Indicator 6.4.1 used in the 2005 C&I-SFM assessment. Despite the growing role of public participation in forest management planning and decision-making processes, there is no potential for it to be directly affected by climate change.

- 2.2. Given expected changes in Canada's climate, describe if and how the indicator's ability to signal progress towards SFM remains unchanged.

Indicator 6.4.1 will not interact directly with climate change, and as such will suffer no decline in any of its traits or the SFM signal it generates. However, the growing public awareness of climate-change issues, especially those that pertain to forest management, may more frequently surface in advisory committee processes. Therefore, climate change may increase the relevance of Indicator 6.4.1.

- 2.3. If an indicator's ability to signal progress towards SFM will be changed, describe if and how the indicator may become worse or better at signalling SFM progress.

The ability of Indicator 6.4.1 to signal SFM progress will not be diminished by climate change.

3. Integrated Climate-Change Assessment

- 3.1. What are the key determinants of the indicator (i.e. what causes it to change when it does change);

a) Among other indicators in the C&I framework?

- **This type and distribution of Crown forest tenures between industry, communities, and Aboriginal peoples are the sole determinant of Indicator 6.4.1 within the C&I framework.**

- b) Among determinants not within the C&I framework?
- **Local citizen advisory committees are one of the key mechanisms for public participation in forest management, and are determinants of Indicator 6.4.1.**
 - **Public participation is most often required by provincial legislation and in the third-party certification process for forest management, making these two things determinants of Indicator 6.4.1.**
 - **Lack of information and the complexity of the issues dealt with by local citizen advisory committees were found to be the chief source of dissatisfaction with the committee process (CCFM, 2006).**
- 3.2. For what other entities is this indicator a key determinant (i.e. when it changes, what other indicators are influenced to change);
- a) Among other indicators in the C&I framework?
- **There are no indicators within the C&I framework that are determined by Indicator 6.4.1.**
- b) Among determinants not within the C&I framework?
- **Public participation is critical to awareness and education in pertinent forest management issues both on a broader national scale and of course in a local-community context. It also facilitates trust and may mitigate potential future conflicts of the public with government and industry.**
 - **Public participation is a widespread tool used in forest management planning processes and contributes to decision-making.**
- 3.3. To what degree can we now, on the basis of extant knowledge, establish how the key determinants interact cumulatively in influencing the indicator?

The satisfaction of local citizens with the public participation process of provincial/territorial governments and forest companies is influenced by several complex social factors. These may range from the values of individual committee members, the adequate dissemination of information, Aboriginal involvement, and tenure structures across Canada's jurisdictions (Parkins et al., 2004; Parkins et al., 2006). According to recent surveys of advisory committee members, the complexity of the issues that are dealt

with and a lack of information to deal with them was the key determinant of dissatisfaction (CCFM, 2006).

- 3.4. Is the indicator largely unrelated to any other, as described by the linkages assessment and evaluation of key determinants? If so, and the indicator was defined as uninfluenced by climate change in the independent assessment, then it can be placed in category one.

Indicator 6.4.1 is almost entirely unrelated to other indicators within the C&I framework. The influence of its key determinants does not suggest any potential for climate change to reduce its ability to signal progress towards SFM. We can therefore assign Indicator 6.4.1 to category one, *Uninfluenced Indicators*.

- 3.5. Do the indirect effects of climate change via the linkages with other indicators influence the indicator's ability to signal SFM, regardless of which category was assigned in the independent climate-change assessment?

Major weather and forest-disturbance events have garnered public attention recently, such as the impact of the mountain pine beetle (*Dendroctonus ponderosae*) on national parks in British Columbia (McFarlane et al., 2006). It is likely that the growing public recognition and acceptance of threats of climate change will be reflected in the public participation process of SFM. This may somewhat increase the relevance of Indicator 6.4.1, though not the degree in which change to Indicator 6.4.1 is necessary.

- 3.6. If the indicator's ability to signal SFM progress remains the same under a changing climate, can we conclude no negative influence and leave it unchanged? These indicators can be placed in category two.

Not applicable.

- 3.7. If the indicator's ability to signal SFM progress deteriorates when one assumes a changing climate, then what modifications are possible or warranted to improve its ability sufficiently for it to remain among the C&I-SFM? These indicators can be placed in category three.

Not applicable.

- 3.8. If no modifications seem possible or warranted, are we ready to recommend abandonment of the indicator? These indicators can be placed in category four.

Not applicable.

- 3.9. If we recommend abandonment, can we identify any new and closely allied indicators that might suit our needs better under climate change? Are there any other reasons for the creation of an additional indicator? These indicators can be placed in category five.

Not applicable.

- 3.10. Have extant climate-change impacts made this indicator more pertinent to SFM (i.e. 2.3 and the mountain pine beetle)? These indicators can be placed in category five or considered for conversion from a supporting to a core indicator (where applicable).

Major climate-change impacts that have held significant public attention, such as the mountain pine beetle outbreak (McFarlane et al., 2006), or the increasing severity and frequency of extreme weather events that are having dramatic effects on human health and infrastructure (Health Canada, 2005; Health Canada, 2010), all act to increase public awareness of the issues associated with climate change.

- 3.11. How should the surviving indicator (the original, modified, or new) be modelled and monitored so that stronger SFM signals may be generated?

Data for the measurement of Indicator 6.4.1 was collected using a national survey of advisory-committee participants in order to gauge their stratification with the committee process (Parkins et al., 2004; CCFM, 2006). Similar surveys have been conducted since the 2005 C&I-SFM assessment (Parkins et al., 2006), which is promising for the monitoring continuity of this otherwise difficult to measure Indicator. Climate change will have no influence on the future monitoring approach to Indicator 6.4.1. However, these surveys have many associated difficulties and biases. For example, the sample consisted of mainly males over 50, and did not include citizens who dropped out of committees due to dissatisfaction (CCFM, 2006).

- 3.12. Does this indicator track an entity whose relationship with climate is regionally variable?

There will be no regional variability in the effectiveness of Indicator 6.4.1 due to climate change.

INDICATOR 6.4.2 RATE OF COMPLIANCE WITH SUSTAINABLE FOREST MANAGEMENT LAWS AND REGULATIONS

1. Linkages Assessment

Table 1.1. Indicators influencing Indicator 6.4.2.

Indicator 6.4.2	Influencing Indicators
First order positive	3.1 and 3.2
First order negative	None
First order bi-directional	6.5.4

Table 1.2. Indicators influenced by Indicator 6.4.2.

Indicator 6.4.2	Influenced Indicators
First order positive	1.2.2, 1.2.3, 1.3.2, 2.5, 3.1, and 3.2
First order negative	1.2.1 and 2.2
First order bi-directional	1.1.1, 2.1, 4.1.1, 4.1.2, 5.3.1, and 5.3.2

- 1.1. Which indicators are influencing and influenced directly (first-order interactions) by the indicator in question? Is the indicator more of a driver of change in other indicators, or being driven by other indicators?

Indicator 6.4.2 is influenced directly by three other indicators pertaining to forest-management standards and guidelines (Indicator 6.5.4) and compliance with them (Indicators 3.1 and 3.2). It influences 14 other indicators, all of which are form the biophysical indicator subset except for Indicators 5.3.1 and 5.3.2. Indicator 6.4.2 is far more a driver of change in other indicators than it is influenced by others.

- 1.2. List the indicators described as ‘relevant indicators under other criteria’ in the 2003 C&I-SFM. Is there any conflict with the interactions described in the matrix?

No other indicators are described as relevant to Indicator 6.4.2 or to fair and effective decision-making within the 2003 C&I-SFM report.

- 1.3. Are there any overlaps or gaps in the relationship with indicators defined in Eddington and colleague’s (2009) report?

The FFEI project is focused on monitoring key species and ecological processes in order to signal and anticipate the response of forest and rangeland to climate change. It does not address policy, laws, standards, or guidelines of forest management, or compliance rates of forest practitioners.

2. Independent Climate-Change Assessment

- 2.1. Provide in detail, a qualitative description of what are the expected direct effects of climate change on the indicator, using a broad representation from the literature.

The legislation developed for SFM and the regulatory approach to enforcement in each province and territory are directed towards protecting a myriad of social, economic, and ecological values. SFM laws and regulations on public land in Canada are some of the World's strictest, and contribute to our global leadership in sustainable forest practices (CCFM, 2010). It will be important to address the impending threats from climate change in these laws and regulations to maintain a leadership role in SFM.

The rapid development of post-Kyoto climate change and carbon policies and regulations has major implications for Canada's forests (Carlson et al., 2010). Consequently, much of the recent developments in climate regulation are centred on forest management recommendations pertaining to the enhancement of forest-ecosystem carbon, reducing deforestation, and increasing afforestation in order to mitigate the effects of climate change (Nabuurs et al., 2007; Carlson et al., 2010). More specific and technical developments to SFM laws and regulations will be critical to manage Canada's forest resources in the face of climate change. This might include developing seed transfer guidelines to assist shifting ranges of tree species and natural adaptation (McKenney et al., 2009) or increasing the rate of salvage harvests in response to the more frequent disturbances (Spittlehouse, 2005). The incredibly broad spectrum of SFM laws and regulation that could be monitored under Indicator 6.4.2 will certainly be influenced by the observed and predicted impacts of climate change.

- 2.2. Given expected changes in Canada's climate, describe if and how the indicator's ability to signal progress towards SFM remains unchanged.

Indicator 6.4.2 will not diminish in its ability to signal SFM progress in a changing climate. As an action indicator pertaining to compliance with SFM laws and regulations, there is a very low potential for indicator decline under climate change. However, given the incredibly broad definition of this Indicator, and high likelihood for climate change to influence forest ecosystems, it will likely increase in relevance. Unlike some other action indicators in the C&I framework whose increasing relevance necessitated modification or the creation of an additional indicator, we feel that no additional action will be necessary in relation to Indicator 6.4.2.

- 2.3. If an indicator's ability to signal progress towards SFM will be changed, describe if and how the indicator may become worse or better at signalling SFM progress.

The ability of Indicator 6.4.2 to signal SFM progress will not decline under climate change.

3. Integrated Climate-Change Assessment

3.1. What are the key determinants of the indicator (i.e. what causes it to change when it does change);

a) Among other indicators in the C&I framework?

- **The update and creation of new ecological standards and guidelines in forest management, as tracked by Indicator 6.5.4, are determinants of Indicator 6.4.2.**
- **There is significant overlap of Indicator 6.4.2 with Indicators 3.1 and 3.2. As such, these Indicators are both in-part determined by and determinants of Indicator 6.4.2.**

b) Among determinants not within the C&I framework?

- **Forest management planning guidelines that are published by natural resource agencies in the different jurisdictions are key determinants of the SFM laws and regulations tracked under Indicator 6.4.2, though not of the compliance with them.**
- **The frequency of audits or compliance checks, and the type and severity of contraventions that governing bodies or regulators administer for noncompliance are determinants of Indicator 6.4.2.**
- **Third-party certification, such as those provided by the Forest Stewardship Council (FSC), Sustainably Forestry Initiative (SFI), and Canadian Standards Association (CSA), are gaining popularity as market-based tools for SFM and may be seen as influential on forest management practices and compliance to SFM laws and regulations.**

3.2. For what other entities is this indicator a key determinant (i.e. when it changes, what other indicators are influenced to change);

a) Among other indicators in the C&I framework?

- **The importance of SFM laws and regulations for maintaining biological diversity and forest-ecosystem condition and productivity is emphasised by the widespread influence of Indicator 6.4.2 on Indicators in Criteria 1 and 2.**
- **The annual harvest of timber and non-timber forest products and, more importantly, the sustainability of those harvest that are tracked by Indicators 5.3.1 and 5.3.2 are influenced by the compliance with SFM laws and regulations.**

- b) Among determinants not within the C&I framework?
- **The goal of SFM laws and regulations is to “maintain or enhance the character and resilience of forest ecosystems, to ensure the optimum use of forest resources, and to support social and cultural interests and needs” (CCFM, 2006, p. 132). As such, Indicator 6.4.2 can be seen as a key function with the ecological, economic, and social spheres of SFM.**

3.3. To what degree can we now, on the basis of extant knowledge, establish how the key determinants interact cumulatively in influencing the indicator?

The cumulative effects of noncompliance with SFM laws and regulations would be substantively quantifiable within forest ecosystems. However, our ability to discern the varying influence of different determinants on the actual compliance with SFM laws and regulations is exceedingly difficult. Likely the influence of new and updated SFM standards and guidelines (Indicator 6.5.4), the intensity of compliance monitoring, and different jurisdictional and corporate forest management guidelines all affect the rate of compliance to varying degrees.

3.4. Is the indicator largely unrelated to any other, as described by the linkages assessment and evaluation of key determinants? If so, and the indicator was defined as uninfluenced by climate change in the independent assessment, then it can be placed in category one.

Despite being a highly interrelated indicator, Indicator 6.4.2 is still free from climate-change influence, largely because it is an action indicator tracking compliance rates. We can therefore assign it to category one, *Uninfluenced Indicators*.

3.5. Do the indirect effects of climate change via the linkages with other indicators influence the indicator’s ability to signal SFM, regardless of which category was assigned in the independent climate-change assessment?

The impacts of climate change on forest ecosystems and the biophysical indicators that monitor them, along with the likely development of new forest management standards and guidelines to promote climate-change adaptation, tracked by Indicator 6.5.4, all increase the relevance of Indicator 6.4.2. However, this is more pertinent to Indicator 6.5.4, and we feel that because this Indicator is tracking compliance rates and not the status of new laws and regulations, it is uninfluenced by climate change.

3.6. If the indicator’s ability to signal SFM progress remains the same under a changing climate, can we conclude no negative influence and leave it unchanged? These indicators can be placed in category two.

Not applicable.

- 3.7. If the indicator's ability to signal SFM progress deteriorates when one assumes a changing climate, then what modifications are possible or warranted to improve its ability sufficiently for it to remain among the C&I-SFM? These indicators can be placed in category three.

Not applicable.

- 3.8. If no modifications seem possible or warranted, are we ready to recommend abandonment of the indicator? These indicators can be placed in category four.

Not applicable.

- 3.9. If we recommend abandonment, can we identify any new and closely allied indicators that might suit our needs better under climate change? Are there any other reasons for the creation of an additional indicator? These indicators can be placed in category five.

Not applicable.

- 3.10. Have extant climate-change impacts made this indicator more pertinent to SFM (i.e. 2.3 and the mountain pine beetle)? These indicators can be placed in category five or considered for conversion from a supporting to a core indicator (where applicable).

Due to the broad nature of Indicator 6.4.2 and its design as an action indicator tracking compliance rates, we can see no climate-change impacts that have specific pertinence to it. However, any of the recent major disturbance events and changes tree physiology and phenology (Williamson et al., 2009) that affect the managed forest ecosystems of Canada have some pertinence to this Indicator.

- 3.11. How should the surviving indicator (the original, modified, or new) be modelled and monitored so that stronger SFM signals may be generated?

Indicator 6.4.2 is monitored through the reporting of compliance rates from the provinces and territories that have the necessary data, which was only eight of Canada's 13 jurisdictions as of the 2005 C&I-SFM assessment (CCFM, 2006). This and the relatively vague and inclusive nature of the Indicator may warrant some refinement to future monitoring initiatives in order to improve its measurability and understandability.

- 3.12. Does this indicator track an entity whose relationship with climate is regionally variable?

The regional variability of climate change has no major implications for the compliance with SFM laws and regulations.

INDICATOR 6.5.1 COVERAGE, ATTRIBUTES, FREQUENCY AND STATISTICAL RELIABILITY OF FOREST INVENTORIES AND

INDICATOR 6.5.2 AVAILABILITY OF FOREST INVENTORY INFORMATION TO THE PUBLIC

1. Linkages Assessment

Table 1.1. Indicators influencing Indicators 6.5.1 and 6.5.2.

Indicator 6.5.1	Influencing Indicators
First order positive	None
First order negative	None
First order bi-directional	None
Indicator 6.5.2	
First order positive	None
First order negative	None
First order bi-directional	None

Table 1.2. Indicators influenced by Indicators 6.5.1 and 6.5.2.

Indicator 6.5.1	Influencing Indicators
First order positive	None
First order negative	None
First order bi-directional	None
Indicator 6.5.2	
First order positive	None
First order negative	None
First order bi-directional	None

- 1.1. Which indicators are influencing and influenced directly (first-order interactions) by the indicator in question? Is the indicator more of a driver of change in other indicators, or being driven by other indicators?

Indicators 6.5.1 and 6.5.2 are action indicators and have no interactions with other indicators within the C&I framework.

- 1.2. List the indicators described as ‘relevant indicators under other criteria’ in the 2003 C&I-SFM. Is there any conflict with the interactions described in the matrix?

There are no other indicators within the C&I framework that are specifically described as relevant to Indicators 6.5.1 or 6.5.2.

- 1.3. Are there any overlaps or gaps in the relationship with indicators defined in Eddington and colleague’s (2009) report?

The FFEI project is focused on monitoring key species and ecological processes in order to signal and anticipate the response of forest and rangeland to climate change. There is no inclusion of the socio-economic dimension of SFM, so there is no overlap between the C&I framework and the Eddington et al. (2009) report.

2. Independent Climate-Change Assessment

- 2.1. Provide in detail, a qualitative description of what are the expected direct effects of climate change on the indicator, using a broad representation from the literature.**

The forest inventories that are monitored under Indicators 6.5.1 and 6.5.2 are forest management unit inventories, which are overseen by jurisdictional natural resource agencies and private firms that primarily use 1:20,000 aerial photography, and Canada's National Forest Inventory (CanFI), which is a cost-effective sample-plot based compilation of available provincial and territorial inventories (CanFI, 2001; CCFM, 2006). Available, reliable, and valid forest inventories are crucial to effective operational decision-making and forest management planning (Thompson et al., 2007), and are becoming more important in management planning for other forest-based services like wildlife habitat and recreation (Rettie et al., 1997).

Remote sensing using light detection and ranging (LIDAR) and high-resolution satellite imagery is a rapidly developing science with great value to the feasibility of forest inventories (Leckie et al., 2003; Wulder et al., 2008). These tools will likely be highly important for monitoring climate-induced changes in forest conditions and the extent of natural disturbances at the national scale (Leckie et al., 2002).

Climate change may be detrimental to the validity of traditional growth and yield models that are used to estimate merchantable volume in forest inventories (Linder, 2000). This is because these models are often empirically based, and thus rely on established growth patterns from stable, historical climate regimes. Forest inventories are also necessary inputs for carbon budget models, such as the CBM-CFS3, which are used to forecast forest-carbon dynamics and net changes in order to track Canada's role in global carbon cycles and climate-change mitigation agreements (Kurz et al., 2009; Williamson et al., 2009).

- 2.2. Given expected changes in Canada's climate, describe if and how the indicator's ability to signal progress towards SFM remains unchanged.**

Indicators 6.5.1 and 6.5.2 will not sustain any declines in their ability to signal our progress towards SFM. The case may be that Indicators 6.5.1 and 6.5.2 increase in relevance due entirely to their role in the measurement of other major climate-change impacts, especially given recent improvements to inventory capacities with new remote-sensing technologies. However, we still regard both these Indicators as fundamentally uninfluenced by climate change.

- 2.3. If an indicator's ability to signal progress towards SFM will be changed, describe if and how the indicator may become worse or better at signalling SFM progress.

There will be no decline in the ability of Indicators 6.5.1 and 6.5.2 to signal SFM progress.

3. Integrated Climate-Change Assessment

- 3.1. What are the key determinants of the indicator (i.e. what causes it to change when it does change);

- a) Among other indicators in the C&I framework?
 - **There are no key determinants of Indicators 6.5.1 and 6.5.2 within the C&I framework.**
- b) Among determinants not within the C&I framework?
 - **The budget and update-frequency of inventories by provincial and territorial natural resource agencies are a key determinant of Indicator 6.5.1.**
 - **Indicator 6.5.2 can be seen as an action indicator, whose key determinants are the applicable policies in the different jurisdictions.**
 - **Operational cruising, or ground-truthing, is an important step in measuring the reliability of forest inventories. The skill and training of forest inventory workers are also determinants of Indicator 6.5.1.**
 - **The increasing availability of spatial data from both jurisdictional natural resource agencies and unaffiliated online data clearinghouses are a key determinant of Indicator 6.5.2.**

- 3.2. For what other entities is this indicator a key determinant (i.e. when it changes, what other indicators are influenced to change);

- a) Among other indicators in the C&I framework?
 - **Forest inventories, and their reliability and availability are not directly linked to any indicators in the C&I framework. However, they are essential to the measurement of many of the biophysical indicators that track some state or condition of Canada's forest.**

- **Reliable and available forest inventories are vital inputs to many different modelling techniques, such as carbon budget models and growth and yield models, and are therefore key factors in their validity. This makes Indicators 6.5.1 and 6.5.2 determinants of Indicators 2.1, 4.1.1, and 4.1.2, though this would not be reflected in the interaction matrix.**

b) Among determinants not within the C&I framework?

- **Forest inventories are key support tools in forest-management planning and effective decision-making, which will also be influenced by their validity, reliability, and availability.**

3.3. To what degree can we now, on the basis of extant knowledge, establish how the key determinants interact cumulatively in influencing the indicator?

The determinants of Indicators 6.5.1 and 6.5.2 are largely centered in the social, economic, and political realms, which makes their cumulative influence incredibly difficult to discern or quantify. The most important interactions for Indicator 6.5.1 are likely between the policies and budgets for forest inventories, update-frequency, and size of the land base being inventoried. Indicator 6.5.2 is essentially only influenced by provincial/territorial or company policies on proprietary rights (for the latter only) and public availability.

3.4. Is the indicator largely unrelated to any other, as described by the linkages assessment and evaluation of key determinants? If so, and the indicator was defined as uninfluenced by climate change in the independent assessment, then it can be placed in category one.

Indicators 6.5.1 and 6.5.2 are action indicators and are not influenced by any other indicators in the C&I framework. The only interaction with climate change is the potential for statistical reliability of some inventory attributes to decline. However, this is relatively external to Indicator 6.5.1 and we can therefore assign both Indicators to category one, *Uninfluenced Indicators*.

3.5. Do the indirect effects of climate change via the linkages with other indicators influence the indicator's ability to signal SFM, regardless of which category was assigned in the independent climate-change assessment?

There are no interactions with other indicators that affect the ability of Indicators 6.5.1 and 6.5.2 to signal SFM progress.

3.6. If the indicator's ability to signal SFM progress remains the same under a changing climate, can we conclude no negative influence and leave it unchanged? These indicators can be placed in category two.

Not applicable. The Indicators have already been assigned to category one.

- 3.7. If the indicator's ability to signal SFM progress deteriorates when one assumes a changing climate, then what modifications are possible or warranted to improve its ability sufficiently for it to remain among the C&I-SFM? These indicators can be placed in category three.

Not applicable.

- 3.8. If no modifications seem possible or warranted, are we ready to recommend abandonment of the indicator? These indicators can be placed in category four.

Not applicable.

- 3.9. If we recommend abandonment, can we identify any new and closely allied indicators that might suit our needs better under climate change? Are there any other reasons for the creation of an additional indicator? These indicators can be placed in category five.

Not applicable.

- 3.10. Have extant climate-change impacts made this indicator more pertinent to SFM (i.e. 2.3 and the mountain pine beetle)? These indicators can be placed in category five or considered for conversion from a supporting to a core indicator (where applicable).

The observed changes in forest productivity, primarily in northern Canada's boreal-tundra ecotone (Zhang et al., 2008) and the aspen parklands of the western Canadian interior (Hogg et al., 2008), have serious implications for traditional methods of estimation for merchantable volume that rely on yield tables and growth and yield models. These methods were developed using historical growth patterns, and as such rely on assumptions of a stable climate.

- 3.11. How should the surviving indicator (the original, modified, or new) be modelled and monitored so that stronger SFM signals may be generated?

The current approach to monitoring Indicators 6.5.1 and 6.5.2 entails reporting from provincial and territorial natural resource agencies for forest management unit inventories. The National Forest Inventory is also used for measuring Indicator 6.5.1, and is a sample-plot based inventory of the entire Country using a compilation of existing inventories from all jurisdictions (CanFI, 2001). Climate change will not necessitate a change in the approach to monitoring these Indicators. However, the different

provincial/territorial natural resource agencies will need to address the influence of climate change on forest growth and productivity in any modelling techniques they rely on.

3.12. Does this indicator track an entity whose relationship with climate is regionally variable?

There will likely be some regional variability in the influence of climate change on Indicators 6.5.1, but not for 6.5.2.

INDICATOR 6.5.3 INVESTMENT IN FOREST RESEARCH, TIMBER PRODUCTS INDUSTRY RESEARCH AND DEVELOPMENT, AND EDUCATION

1. Linkages Assessment

Table 1.1. Indicators influencing Indicator 6.5.3.

Indicator 6.5.3	Influencing Indicators
First order positive	5.3.3
First order negative	None
First order bi-directional	None

Table 1.2. Indicators influenced by Indicator 6.5.3.

Indicator 6.5.3	Influenced Indicators
First order positive	5.1.2, 5.1.5, 5.3.3, 5.3.4, 6.2.1, and 6.3.2
First order negative	None
First order bi-directional	6.5.4

- 1.1. Which indicators are influencing and influenced directly (first-order interactions) by the indicator in question? Is the indicator more of a driver of change in other indicators, or being driven by other indicators?

Indicator 6.5.3 is only influenced by one other indicator, 5.3.3, which is by no means a highly influential relationship. It influences seven other Indicators from Criteria 5 and 6. Indicator 6.5.3 is much more of a driver of change in socioeconomic indicators than it is driven to change by other indicators.

- 1.2. List the indicators described as ‘relevant indicators under other criteria’ in the 2003 C&I-SFM. Is there any conflict with the interactions described in the matrix?

Investment in forest-sector research and development is described as highly relevant to new sustainable forest management standards and guidelines, and compliance with them, measured under Indicators 3.1, 3.2, and 6.4.2. It is also described as significant to the economic sustainability of forest-based activities, tracked by indicators in Elements 5.1 and 5.3.

- 1.3. Are there any overlaps or gaps in the relationship with indicators defined in Eddington and colleague’s (2009) report?

The FFEI project is focused on monitoring key species and ecological processes in order to signal and anticipate the response of forest and rangeland to climate change. There is no inclusion of the socio-economic dimension of SFM, so there is no overlap between the C&I framework and the Eddington et al. (2009) report.

2. Independent Climate-Change Assessment

- 2.1. Provide in detail, a qualitative description of what are the expected direct effects of climate change on the indicator, using a broad representation from the literature.

Investment in forest science and technology (S&T), timber products research and development (R&D), and education by governments, industry, academic institutions, and various other non-profit organizations is a major contributor to economic welfare in the forest sector and societal well-being (CCFM, 2006). It is also driving force behind industry progress and innovation. There are many new investments in forest R&D that pertain to climate change in Canada (CCFM, 2009). For example, in Alberta a collaborative partnership has been formed by between the Governments of Canada and Alberta and Alberta Innovates to create the \$15 million investment in the Alberta Biomaterials Development Centre (ABDC; Government of Canada, 2010). This centre is focused on developing low-emissions bioproducts and bioenergy sources from wood fibre and feedstock (CCFM, 2009; Government of Canada, 2010).

Investment in climate-change mitigation has been relatively widespread since the formation of international agreements to reduce the greenhouse gas emissions causing climate change, such as those pertaining to the United Nations Framework Convention on Climate Change (UNFCCC) and Kyoto Protocol (Grissom et al., 2000; Noss, 2001). However, forest-sector adaptation to climate change is likely far more critical for reducing the vulnerability of Canada's forests and their management, and has received less attention than mitigation in new policy formation (Johnston et al., 2010). The majority of Canada's jurisdictions have now initiated some form of climate-change adaptation strategy for forest management in recent years (Johnston et al., 2010). For example, the Ontario Ministry of Natural Resources (OMNR) has initiated the Climate Change Strategy and Action Plan (OMNR, 2006) and British Columbia has developed their Future Forest Ecosystem Initiative (FFEI), which includes the FFEI indicator set outlined by Eddington and colleagues (Spittlehouse, 2008; Eddington et al., 2009).

- 2.2. Given expected changes in Canada's climate, describe if and how the indicator's ability to signal progress towards SFM remains unchanged.

The ability of Indicator 6.5.3 to signal SMF progress will not remain the same under climate change.

- 2.3. If an indicator's ability to signal progress towards SFM will be changed, describe if and how the indicator may become worse or better at signalling SFM progress.

Indicator 6.5.3 is an action indicator, and as with most other action indicators in the C&I framework, there is no decline in any of its traits under climate change. The key influence of climate change on Indicator 6.5.3 is a considerable increase in its relevance, because of the likelihood for new major research initiatives into climate-change adaptation.

3. Integrated Climate-Change Assessment

3.1. What are the key determinants of the indicator (i.e. what causes it to change when it does change);

a) Among other indicators in the C&I framework?

- **The only determinant of Indicator 6.5.3 within the C&I framework is the return on capital employed (ROCE), tracked by Indicator 5.3.3, as a high ROCE attracts more capital investment (CCFM, 2006). However, Indicator 5.3.3 is by no means the key determinant.**

b) Among determinants not within the C&I framework?

- **Indicator 6.5.3 is primarily determined by factors that are external to the C&I framework. Industry, government, academic institutions, and research institutes, and of course their funding, are all major determinants of forest-sector R&D, education, and S&T.**

3.2. For what other entities is this indicator a key determinant (i.e. when it changes, what other indicators are influenced to change);

a) Among other indicators in the C&I framework?

- **Government and industry investment in secondary manufacturing and some non-timber forest products is an important stimulus for these growing industries.**
- **Investment in R&D and S&T is a major determinant of industry productivity and ROCE, as tracked by Indicators 5.3.4 and 5.3.3, respectively.**
- **Indicator 6.5.3 could also be seen as related to research on traditional land uses, and thus a partial determinant of Indicator 6.2.1.**
- **Investment in education is of course a determinant of Indicator 6.3.2.**
- **Investment in forest research is a driver in the development of new ecological standards and guidelines in forest management, as tracked by Indicator 6.5.4.**

b) Among determinants not within the C&I framework?

- **Indicator 6.5.3 is a key determinant of creativity and innovation, and ultimately performance, within the forest sector.**

- **Indicator 6.5.3, in collaboration with Indicator 6.5.4, deals with the incorporation of new and developing knowledge into the forest sector.**
- **R&D and S&T are major drivers of Canada's competitiveness in global forest product markets.**

3.3. To what degree can we now, on the basis of extant knowledge, establish how the key determinants interact cumulatively in influencing the indicator?

The key determining factor influencing Indicator 6.5.3 is the R&D and S&T funding primarily from government and industry (CCFM, 2006). It is not possible to fully delineate and quantify the cumulative factors influencing this process. However, some important influences are likely from the policies of current governments, the strength of Canada's forest sector, and their competitiveness in international markets.

3.4. Is the indicator largely unrelated to any other, as described by the linkages assessment and evaluation of key determinants? If so, and the indicator was defined as uninfluenced by climate change in the independent assessment, then it can be placed in category one.

Indicator 6.5.3 is an important driver of several socioeconomic indicators, but is largely determined by external forces not inclusive to the C&I framework. However, because of the increasing relevance of the Indicator under climate change we will not assign it to category one.

3.5. Do the indirect effects of climate change via the linkages with other indicators influence the indicator's ability to signal SFM, regardless of which category was assigned in the independent climate-change assessment?

The described effects of climate change on Indicator 6.5.3 can all be attributed to direct influence.

3.6. If the indicator's ability to signal SFM progress remains the same under a changing climate, can we conclude no negative influence and leave it unchanged? These indicators can be placed in category two.

Not applicable. While Indicator 6.5.3 does not decline in its ability to signal SFM progress, we feel that the increase in relevance may warrant some modification to the Indicator.

3.7. If the indicator's ability to signal SFM progress deteriorates when one assumes a changing climate, then what modifications are possible or warranted to improve its ability

sufficiently for it to remain among the C&I-SFM? These indicators can be placed in category three.

In order to track new investment and research into climate-change adaptation that is responsible for the increasing relevance of Indicator 6.5.3, we recommend modifying the Indicator to *Investment in Forest Research, Timber Products Industry Research and Development, Education, and Climate-change Adaptation and Mitigation*.

- 3.8. If no modifications seem possible or warranted, are we ready to recommend abandonment of the indicator? These indicators can be placed in category four.

Not applicable.

- 3.9. If we recommend abandonment, can we identify any new and closely allied indicators that might suit our needs better under climate change? Are there any other reasons for the creation of an additional indicator? These indicators can be placed in category five.

Not applicable.

- 3.10. Have extant climate-change impacts made this indicator more pertinent to SFM (i.e. 2.3 and the mountain pine beetle)? These indicators can be placed in category five or considered for conversion from a supporting to a core indicator (where applicable).

There are numerous examples of natural resource agencies in Canada's jurisdictions investing in strategies for climate-change adaptation in forest management (Johnston et al., 2010). A prominent example that pertains to Indicator 6.5.3 is the establishment of Regional Adaptation Collaboratives (RACs) by Natural Resources Canada. The RACs program is a three-year initiative, totalling \$30 million in investment, which is aimed at promoting action around climate-change adaptation and providing support for regional decision-makers (NRCan, 2011). RACs have been established in four of the five target regions in Canada, which include Atlantic Canada, Quebec, Ontario, the Prairies, and British Columbia, with action in Northern Canada expected to begin soon (NRCan, 2011).

- 3.11. How should the surviving indicator (the original, modified, or new) be modelled and monitored so that stronger SFM signals may be generated?

Indicator 6.5.3 is measured primarily with the federal, provincial, and industry investment in science and technology, and the percentage of employees with secondary school diplomas, trade/college diplomas, and bachelor degrees or higher. These data are collected by Statistics Canada, which is a reliable source of data for future monitoring and assessment, regardless of climate change. Several surveys also contribute to the SFM signal of Indicator 6.5.3, such as the Statistics Canada Survey of Innovation from 2003.

3.12. Does this indicator track an entity whose relationship with climate is regionally variable?

Regional variability in the influence of climate change will not affect Indicator 6.5.3.

INDICATOR 6.5.4 STATUS OF NEW OR UPDATED FOREST MANAGEMENT GUIDELINES AND STANDARDS RELATED TO ECOLOGICAL ISSUES

1. Linkages Assessment

Table 1.1. Indicators influencing Indicator 6.5.4.

Indicator 6.5.4	Influencing Indicators
First order positive	None
First order negative	None
First order bi-directional	1.2.1, 1.3.2, 2.2, 2.3, 2.5, and 6.5.3

Table 1.2. Indicators influenced by Indicator 6.5.4.

Indicator 6.5.4	Influenced Indicators
First order positive	None
First order negative	None
First order bi-directional	1.2.1, 1.3.1, 1.3.2, 2.2, 2.3, 2.5, 3.1, 3.2, 5.3.1, 5.3.2, and 6.4.2

- 1.1. Which indicators are influencing and influenced directly (first-order interactions) by the indicator in question? Is the indicator more of a driver of change in other indicators, or being driven by other indicators?

Indicator 6.5.4 influences 11 other indicators directly, from all Criteria except Criterion 4. It is influenced by six other indicators, primarily from Criteria 1 and 2. All of the first-order interactions of Indicator 6.5.4 are bi-directional. It is also much more of a driver of change than driven to change by other indicators.

- 1.2. List the indicators described as ‘relevant indicators under other criteria’ in the 2003 C&I-SFM. Is there any conflict with the interactions described in the matrix?

Information on new and updated ecological standards and guidelines for forest management is described as relevant for compliance rates with soil disturbance standards (Indicator 3.1) and road construction, stream crossing, and riparian zone standards (Indicator 3.2) in the 2003 C&I-SFM.

- 1.3. Are there any overlaps or gaps in the relationship with indicators defined in Eddington and colleague’s (2009) report?

The FFEI project is focused on monitoring key species and ecological processes in order to signal and anticipate the response of forest and rangeland to climate change. There is no inclusion of the socio-economic dimension of SFM, so there is no overlap between the C&I framework and the Eddington et al. (2009) report.

2. Independent Climate-Change Assessment

- 2.1. Provide in detail, a qualitative description of what are the expected direct effects of climate change on the indicator, using a broad representation from the literature.

A key agent of change for the status of new or updated forest management guidelines and standards related to ecological issues is the advancement of forest science and research, and thus our understanding of forest ecology and the influence of human activities on forest ecosystems. In recent decades there have been numerous instances of new forest management standards and regulations resulting from our expanding knowledge, all of which could be monitored under Indicator 6.5.4. For example, riparian ecosystems are rich in structural and biological diversity and are vital to the hydrological functioning of forest watersheds (Naiman et al., 1993). The growing recognition of the impacts of forest management on water quality and the importance of riparian buffer zones to mitigate these impacts has been the key driver in the development of many recent forest management standards and guidelines for buffer widths in the majority of Canada's jurisdictions (Swank et al., 2001; Lee et al., 2004).

Climate-change impacts on forest ecosystems and their management are essentially at the forefront of current forest research, along with the adaptation to climate change in management activities (Spittlehouse & Stewart, 2003; Johnston et al., 2009; Johnston et al., 2010). Most provinces and territories have initiated climate-change adaptation strategies in the past decade, such as the Climate Change Strategy and Action Plan developed by the Ontario Ministry of Natural Resources (OMNR, 2006) and of course British Columbia's Future Forest Ecosystem Initiative (FFEI), which includes the FFEI indicator set outlined by Eddington and colleagues (Spittlehouse, 2008; Eddington et al., 2009). Climate change will have major effects on forest ecology across Canada, and therefore on the standards and guidelines pertaining to ecological issues in forest management, which greatly increases the relevance of Indicator 6.5.4.

- 2.2. Given expected changes in Canada's climate, describe if and how the indicator's ability to signal progress towards SFM remains unchanged.

Indicator 6.5.4 will not remain the same in its ability to signal our progress towards SFM.

- 2.3. If an indicator's ability to signal progress towards SFM will be changed, describe if and how the indicator may become worse or better at signalling SFM progress.

Indicator 6.5.4 suffers from relatively low understandability and subsequently low predictability, which is partially reflected in the linkages assessment where all interactions were bi-directional. However, these symptoms will not be exacerbated by the changing climate. The status of new or updated standards and guidelines could be described as a context indicator, as it tracks "phenomena to which local management may react, but which cannot be influenced solely from the local level" (Duinker, 2001, p. 17). Because the

CCFM C&I framework is designed at the national scale, and given the monitoring approach in the 2005 C&I-SFM assessment (CCFM, 2006), we prefer to label it as an action indicator. As an action indicator, the major influence of climate change on Indicator 6.5.4 is an increase in relevance.

3. Integrated Climate-Change Assessment

3.1. What are the key determinants of the indicator (i.e. what causes it to change when it does change);

- a) Among other indicators in the C&I framework?**
 - The status of endangered wildlife and tree species, as tracked by Indicators 1.2.1 and 1.3.2, are determinants of Indicator 6.5.4.**
 - The proportion of timber harvest area that is successfully regenerated (Indicator 2.5) may also be a driver of new forest management standards and guidelines.**
 - Afforestation initiatives, tracked in-part by Indicator 2.2, often are initiated by new forest management standards and guidelines, making them a determinant of Indicator 6.5.4.**
 - Investment in new forest research (Indicator 6.5.3) is a key determinant of new and updated forest management standards and guidelines.**

- b) Among determinants not within the C&I framework?**
 - The growing social consciousness of ecological issues, biological diversity, and sustainable development, and its influence on policies pertaining to natural-resource management could easily be seen as a key determinant of Indicator 6.5.4.**

3.2. For what other entities is this indicator a key determinant (i.e. when it changes, what other indicators are influenced to change);

- a) Among other indicators in the C&I framework?**
 - Indicator 6.5.4 is a highly encompassing and influential indicator for forest management activities, and as such is a key determinant for the majority of the forest management action indicators within the C&I framework. These include Indicators 1.3.1, 1.3.2, 3.1, 3.2, and 6.5.3.**

- **New standards and guidelines pertaining to ecological issues may also be successful in minimizing the risk-level assigned to forest-associated species at risk, making Indicator 6.5.4 a determinant of Indicator 1.2.1.**

b) Among determinants not within the C&I framework?

- **One goal of Indicator 6.5.4 is to assess the progress made by provincial and territorial resource agencies towards higher ecological standards, and the effectiveness of incorporating ecological research in forest management regulations.**
- **Indicator 6.5.4 is a key determinant in the creation of forest management plans by practitioners, which is a highly recognized building block of SFM, as they lay out key objectives for the maintenance of biological diversity, amongst other things.**

3.3. To what degree can we now, on the basis of extant knowledge, establish how the key determinants interact cumulatively in influencing the indicator?

It is exceedingly difficult to discern the cumulative influence of these determinants on Indicator 6.5.4. The key determinant of this Indicator is the advancement of forest research pertaining to ecological issues, which is tracked under Indicator 6.5.3. The cumulative influence of ecological stressors, the public awareness of issues, and socio-political action around these issues all interact to influence Indicators 6.5.3 and 6.5.4.

3.4. Is the indicator largely unrelated to any other, as described by the linkages assessment and evaluation of key determinants? If so, and the indicator was defined as uninfluenced by climate change in the independent assessment, then it can be placed in category one.

Indicator 6.5.4 is highly related to other indicators in the C&I framework, especially to biophysical ones, which is rare amongst the socioeconomic indicators. We do not recommend assigning it to category one.

3.5. Do the indirect effects of climate change via the linkages with other indicators influence the indicator's ability to signal SFM, regardless of which category was assigned in the independent climate-change assessment?

With indicators that track human decision-making and actions it is difficult to discern between direct and indirect climate-change influence. Regardless, global environmental change, and thus the influence of climate change on all biophysical state indicators in the C&I framework, is the pathway in which Indicator 6.5.4 is affected.

- 3.6. If the indicator's ability to signal SFM progress remains the same under a changing climate, can we conclude no negative influence and leave it unchanged? These indicators can be placed in category two.

The ability of Indicator 6.5.4 to signal SFM progress does not diminish under climate change. However, the increase in relevance necessitates some modification to the indicator.

- 3.7. If the indicator's ability to signal SFM progress deteriorates when one assumes a changing climate, then what modifications are possible or warranted to improve its ability sufficiently for it to remain among the C&I-SFM? These indicators can be placed in category three.

Indicator 6.5.4 is a broad and encompassing indicator that because of its breadth and relatedness with other indicators was influenced by climate change. Specifically, this action indicator increased in relevance because of the myriad of ecological issues expected and currently arising from climate change. In response to this, we recommend modifying the indicator so that the development of new standards and guidelines pertaining to ecological issues also address those ecological issues caused by the changing climate.

- 3.8. If no modifications seem possible or warranted, are we ready to recommend abandonment of the indicator? These indicators can be placed in category four.

Not applicable. We are not ready to recommend abandonment of Indicator 6.5.4.

- 3.9. If we recommend abandonment, can we identify any new and closely allied indicators that might suit our needs better under climate change? Are there any other reasons for the creation of an additional indicator? These indicators can be placed in category five.

Not applicable.

- 3.10. Have extant climate-change impacts made this indicator more pertinent to SFM (i.e. 2.3 and the mountain pine beetle)? These indicators can be placed in category five or considered for conversion from a supporting to a core indicator (where applicable).

Examples of natural resource agencies in Canada's jurisdictions developing new standards and guidelines for climate-change adaptation in forest management are becoming more commonplace (Johnston et al., 2010). However, the vast majority of these initiatives are still in the research phase.

- 3.11. How should the surviving indicator (the original, modified, or new) be modelled and monitored so that stronger SFM signals may be generated?

The most feasible manner in which to monitor the modified Indicator 6.5.4 is likely a qualitative description of different programs and initiatives in each provincial/territorial jurisdiction of Canada. While this is not ideal because it cannot be related to a target or goal (Duinker et al., 2001), it is likely the only practical and feasible monitoring approach to this relatively broad and comprehensive Indicator.

3.12. Does this indicator track an entity whose relationship with climate is regionally variable?

The implications of climate change for the development and update of forest management standards and guidelines will vary between regions.

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