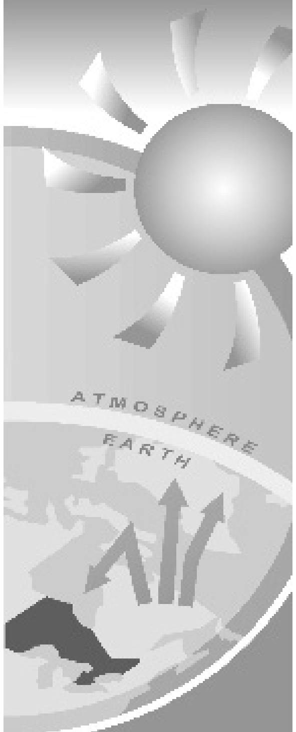
Ministry of Natural Resources

38

CLIMATE CHANGE RESEARCH REPORT

CCRR-38



Responding to Climate Change Through Partnership

Monitoring Programs Sponsored by the Ontario Ministry of Natural Resources and their Relevance to Climate Change

Ontario

Sustainability in a Changing Climate: An Overview of MNR's Climate Change Strategy (2011-2014)

Climate change will affect all MNR programs and the natural resources for which it has responsibility. This strategy confirms MNR's commitment to the Ontario government's climate change initiatives such as the Go Green Action Plan on Climate Change and outlines research and management program priorities for the 2011-2014 period.

Theme 1: Understand Climate Change
MNR will gather, manage, and share information and knowledge about how ecosystem composition, structure and function – and the people who live and work in them – will be affected by a changing climate. Strategies:

- Communicate internally and externally to build awareness of the known and potential impacts of climate change and mitigation and adaptation options available to Ontarians.
- Monitor and assess ecosystem and resource conditions to manage for climate change in collaboration with other agencies and organizations.
- Undertake and support research designed to improve understanding of climate change, including improved temperature and precipitation projections, ecosystem vulnerability assessments, and improved models of the carbon budget and ecosystem processes in the managed forest, the settled landscapes of southern Ontario, and the forests and wetlands of the Far North.
- Transfer science and understanding to decision-makers to enhance comprehensive planning and management in a rapidly changing climate.

Theme 2: Mitigate Climate Change
MNR will reduce greenhouse gas emissions in support of Ontario's greenhouse gas emission reduction goals. Strategies:

- Continue to reduce emissions from MNR operations though vehicle fleet renewal, converting to other high fuel efficiency/low-emissions equipment, demonstrating leadership in energy-efficient facility development, promoting green building materials and fostering a green organizational culture.
- Facilitate the development of renewable energy by collaborating with other Ministries to promote the value of Ontario's resources as potential green energy sources, making Crown land available for renewable energy development, and working with proponents to ensure that renewable energy developments are consistent with approval requirements and that other Ministry priorities are considered.
- Provide leadership and support to resource users and industries to reduce carbon emissions and increase carbon storage by undertaking afforestation, protecting natural heritage areas, exploring opportunities for forest carbon management to increase carbon uptake, and promoting the increased use of wood products over energy-intensive, non-renewable alternatives.
- Help resource users and partners participate in a carbon offset market, by working with our partners to ensure that a robust trading system is in place based on rules established in Ontario (and potentially in other jurisdictions), continuing to examine the mitigation potential of forest carbon management in Ontario, and participating in the development of protocols and policies for forest and land-based carbon offset credits.

Theme 3: Help Ontarians Adapt
MNR will provide advice and tools and techniques to help Ontarians adapt to climate change. Strategies include:

- Maintain and enhance emergency management capability to protect life and property during extreme events such as flooding, drought, blowdown and wildfire.
- Use scenarios and vulnerability analyses to develop and employ adaptive solutions to known and emerging issues.
- Encourage and support industries, resource users and communities to adapt, by helping to develop understanding and capabilities of partners to adapt their practices and resource use in a changing climate.
- Evaluate and adjust policies and legislation to respond to climate change challenges.

Monitoring Programs Sponsored by the Ontario Ministry of Natural Resources and their Relevance to Climate Change

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2014

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Summary

Ontario's climate is warming and becoming increasingly variable. The collective effects of continued warming and increased occurrences of extreme events are expected to change ecosystem composition, structure, and function, with significant social and ecological ramifications throughout Ontario. An important aspect of any decision to manage natural resources given a changing climate includes a commitment to monitor social and ecological change and the success of mitigative and adaptive decisions. The intent of this project was to evaluate the relevance of monitoring programs sponsored by the Ontario Ministry of Natural Resources by (1) identifying key indicators that can be used to measure climate change and its effects, (2) evaluating ongoing long-term monitoring programs to identify those that support indicators of change, (3) determining where information to support indicators is lacking, and (4) providing recommendations on how to improve the monitoring of climate change effects.

Résumé

Les programmes de contrôle parrainés par le ministère des Richesses naturelles de l'Ontario et leur pertinence relativement au changement climatique

Le climat de l'Ontario se réchauffe et devient de plus en plus variable. On s'attend à ce que les effets collectifs d'un réchauffement constant et de la fréquence croissante d'événements extrêmes modifient la composition, la structure et la fonction des écosystèmes, avec des conséquences sociales et écologiques importantes dans tout l'Ontario. Un engagement à contrôler le changement social et économique, et le succès de décisions d'atténuation et d'adaptation, sont un aspect important de toute décision de gérer les ressources naturelles compte tenu du changement climatique. Ce projet avait pour but d'évaluer la pertinence de programmes de contrôle parrainés par le ministère des Richesses naturelles de l'Ontario, (1) en déterminant des indicateurs clés pouvant être utilisés pour mesurer le changement climatique et ses conséquences, (2) en évaluant les programmes de contrôle à long terme en cours afin de déterminer ceux qui permettent de vérifier les indicateurs de changement, (3) en déterminant où manque l'information pour utiliser les indicateurs, et (4) en faisant des recommandations sur la façon d'améliorer le contrôle des conséquences du changement climatique.

Acknowledgements

This work would not have been possible without the advice, support, and contributions of the project steering committee members: Frank Addante, Alan Dextrase, Dave Ethridge, Jenny Gleeson, Paul Gray, Rachelle Lalonde, Gary Nielsen, Murray Radford, Silvia Strobl, Jane Toppozini, Bill Towill, and Bob Watt. The authors are also grateful for the contributions from experts whose collective expertise was invaluable to this project: lakes and streams: David Evans, Nigel Lester, Mark Ridgway, Brian Shuter, and Les Stanfield; terrestrial vegetation: Wasyl Bakowsky, Steve Colombo, Bill Dalton, Mike McMurtry, Scott McPherson, Danijela Puric-Mladenovic, Bill Parker, Jim Steele, and Richard Wilson; wetlands: Harold Lee, Jim McLaughlin, Brian Potter, Peter Uhlig, Regina Varrin, and Sandra Wawryszyn; wildlife: Ken Abraham, Jeff Bowman, Bill Crins, Joe Crowley, Colin Jones, Mike Oldham, Rob Rempel, Taylor Scarr, Dan Rowlinson and Don Sutherland; and biodiversity: Alan Dextrase and Terese McIntosh. Special thanks to Kim Taylor for help with the survey design and to Kate Johnston and Cathy Starr for communications and editorial support. The authors thank Michael Gatt, Lindsay Kingdon, Glen Brown, and Paul Gray for reviewing an earlier version of the manuscript. Thanks to Trudy Vaittinen for report design and layout.

Contents

1.0 Introduction

Changing temperatures and changing precipitation patterns are modifying habitats and jeopardizing the survival of many species throughout the world (Reid et al. 2005, Rockström et al. 2009, Cardinale et al. 2012). Scientists also anticipate that novel ecosystems will emerge as asynchronies between major climatic gradients develop (Gray 2005, Varrin et al. 2007, Williams and Jackson 2007, Nituch and Bowman 2013). In Ontario, many species have been adjusting their distribution (e.g., northward extension of range) and life cycle dynamics (e.g., earlier and longer breeding season) for years (Bowman et al. 2005, Varrin et al. 2007, Catling and Oldham 2011, Nituch and Bowman 2013, Natel et al. in prep.). Given that change results from genetic, physiological, and ecological variations that can coalesce into effects with significant social and ecological ramifications, the collection and analysis of data within a scientifically sound framework over time is critical to informed decisionmaking. Effective monitoring is characterized by long-term sampling that generates statistically valid results to effectively inform policy and research priorities (Francis et al. 2009). As temperatures continue to change, practitioners will increasingly require access to robust long-term data and information with which they can assess change and support commitments to manage for climate change (Expert Panel on Climate Change Adaptation 2009, Government of Ontario 2011).

The Ontario Ministry of Natural Resources (MNR) employs a strategy, *Sustainability in a Changing Climate*, which when implemented will help decisionmakers understand the effects of climate change on Ontario's natural assets, mitigate the effects of climate change, and help Ontarians adapt to and prepare for the effects of climate change (OMNR 2011). Long-term monitoring is critical to the successful implementation of all three strategic themes. The intent of this study was to evaluate the relevance of MNR sponsored monitoring programs by identifying key indicators to measure climate change and its effects, long-term monitoring programs that support indicators of change, and where information to support indicators is lacking, as well as providing recommendations for improving monitoring programs to ensure they capture the effects of climate change.

2.0 Methods

The study was completed in two phases: identifying and prioritizing the indicators and measurement variables followed by determining whether the priority indicators were being/could be assessed within ongoing monitoring programs sponsored by MNR.

2.1 Indicators

The first phase of the study was completed in two steps by identifying indicators and describing measurement variables for each indicator (Figure 1).

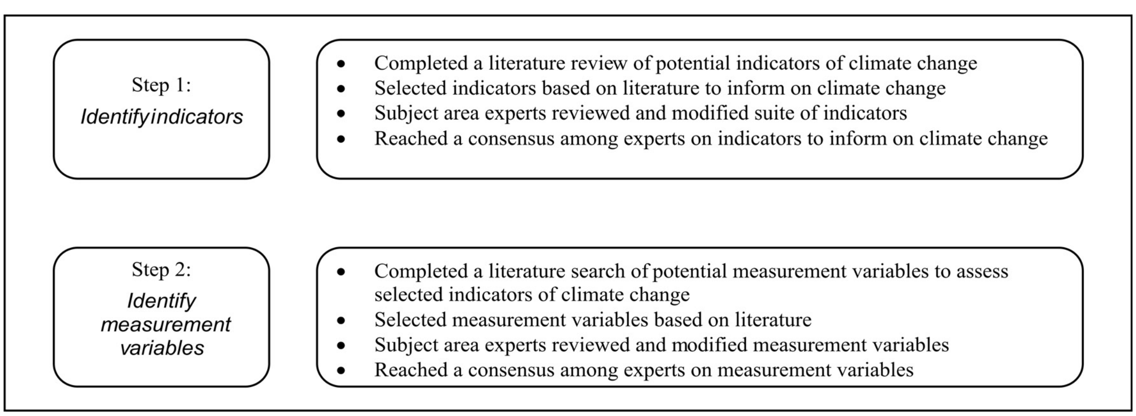

Figure 1. *Approach used to identify a suite of key indicators of climate change and climate change effects on Ontario's natural resources.*

A literature review was used to compile a list of potential indicators of climate change and its effects. Subject area experts assessed the potential indicators using nine criteria ranging from ecological significance to cost effectiveness (Table 1). Experts ranked the overall importance of each indicator in helping practitioners understand the effects of climate change. Of particular interest were indicators applicable to all or most of Ontario's ecological regions for trend reporting at the provincial scale. Subsequently, subject area experts identified 21 indicators. The indicators were organized into response, stressor, and mitigation indicator categories. A response indicator describes a natural asset's response to climate change. Response indicators were further classified into four ecological themes: lakes and streams, terrestrial vegetation, wetlands, and wildlife. Stressor indicators denote changes in climate (e.g., temperature, precipitation, and drought), and mitigation indicators describe the outcome of management decisions and actions in mitigating the effects of climate change.

Table 1. *Criteria for selecting indicators of climate change (Dale and Beyeler 2001, Eddington et al. 2009, Gebhardt at al. 2010, Tegler et al. 2001, and Wicks et al. 2010).*

Criteria	Explanation
Climate change	Does the indicator differentiate between changes induced by anthropogenically-induced climate change and changes resulting from natural cycles and trends? Is the indicator effective at tracking climate change and/or climate impacts over time?
Scope	Is the indicator relevant to identifying, understanding, or monitoring climatic-driven changes in Ontario's ecoregions?
Ecologically significant	Does the indicator measure responses of key ecological characteristics, ecological processes, and/or species assemblages?
Informs management	Is the indicator relevant to a management response to climate change?
Measurable	Can the indicator be measured at multiple sites and be re-measured at regular intervals? Can data be collected by anyone who has appropriate training or a detailed guide, using common field equipment)?
Cost effective	Can the indicator be measured in a cost effective manner? Can the indicator be used to addresses multiple business needs (i.e., forest management, biodiversity, climate change)?
Spatially explicit	Can the indicator be mapped and spatially interpreted?
Understandable	Is the indicator easy to understand, intuitive, and easy to explain to non-scientists?
Uncertainty	Is the level of uncertainty known and can it be communicated effectively?

For each indicator, one or more measurement variables were selected. Measurement variables are specific characteristics of an ecosystem, species, or species assemblage. Methods used to select measurement variables were similar to those used to identify and select indicators. Measurement variables were evaluated by four multi-disciplinary teams based on expertise in one of the ecological themes (Tables 2 and 3). While the 21 indicators presented in this report do not represent an exhaustive list, they are included as best bet indicators to help practitioners understand the effects of climate change on Ontario's natural resources.

2.2 Comparing climate change monitoring needs with information collected within MNR's long-term monitoring programs

The second phase of the study involved determining relevant MNR monitoring programs and identifying which of the indicators they addressed. Historically, the MNR has designed and established a variety of monitoring programs at different spatial and temporal scales to address specific business needs. While none of the programs were specifically designed to monitor the effects of climate change, some do measure indicators that help understand the effects of climate change. The approach for determining which monitoring programs were relevant to the study was to compile a catalogue of monitoring programs within MNR and ask program managers to complete a questionnaire about their programs. Criteria developed by Lindenmayer and Likens (2010a,b) were then used to determine which would be considered long-term ecological monitoring programs (Table 4). Of 122 programs assessed, 88 qualified as long-term ecological monitoring programs, 80 of which are currently operational.

The 80 programs were assessed using the 21 climate change indicators identified by the experts in phase 1 (see Tables 2 and 3). A monitoring program was deemed relevant if it provided information about at least one of the measurement variables of a given indicator. Only provincial scale monitoring programs were considered for provincial level indicators. For regional indicators, both provincial and regional monitoring programs were examined.

Table 2. *Characteristics of an effective long-term ecological monitoring program (adapted from Lindenmayer and Likens 2010a,b).*

Type	Characteristic
Essential	• Data collected at regular intervals
	• Data collected over a long period (minimum 10 years)
	• Data are spatially explicit
	• Design is statistically sound with appropriate replication
General	• Questions are well defined and can be investigated following the scientific method
	• Measurement variables are well defined
	• Relevant to resource and ecosystem management, and the mandate of the organization
	• Data collected over an appropriate spatial extent
	• Sampling intensity appropriate for the variables being measured
	• Supported by organizational policy and science
	• Leadership is stable
	• Resources are sufficient resources (human and financial)
	• Data and information management support are continuous
	• Documented and communicated

3.0 Results

3.1 Response indicators

Coastal wetlands

Trends in the extent and quality of marine and Great Lakes coastal wetlands inform biome-level conditions in a changing climate (Federal, Provincial, and Territorial Governments of Canada 2010). Increasing evaporation and changes in precipitation and snow cover patterns are expected to alter water levels on inland lakes and rivers. Lower water levels will affect the distribution and abundance of coastal wetlands (Mortsch et al. 2006) and the species that rely on them for habitat. Marine coastal wetlands likely will be inundated and lost as sea levels rise. By 2100 about 20% of the world's current coastal wetlands could be lost to changing water levels (Gitay et al. 2002). This is less of a concern along the James Bay and Hudson Bay coast because of the high rate of isostatic rebound (Sella et al. 2007). However, in the long-term, rising sea levels, increased wave action, and storm surges will affect Ontario's marine coastline (Martini et al. 2009, Abraham et al. 2011).

Measurement variables include:

a) extent of coastal wetlands
b) water quality of Great Lakes coastal wetlands
c) water quality of marine coastal wetlands

Distribution of diseases, parasites, and pests

Successful invasive diseases and parasites will alter ecosystem composition, structure, and function (Hofmeister et al. 2010) with significant socio-economic ramifications. Warmer temperatures will provide suitable bioclimates in areas historically too cold for parasites and disease vectors such as insects and arachnids (Ayres and Lombardero 2000, Hofmeister et al. 2010). For example, the black legged tick (*Ixodes scapularis*), a vector of Lyme disease (*Borrelia burgdorferi*), continues to expand in Ontario and Manitoba (Ogden et al. 2009), and climate model-scenario projections suggest that the disease will reach Ontario's Far North by 2100.

Insect survival and productivity is directly related to temperature and warmer summers in in Canadian forests will accelerate insect development rates (Johnston et al. 2009). Some insects will shift from completing one generation every two years to completing one generation every year, which will contribute to large-scale outbreaks. Indirect effects of climate change on insects include phenological shifts in life cycle dynamics and relationships with predators such as birds, and prevalence of parasites and diseases (Johnston et al. 2009). Earlier and warmer spring weather will result in longer outbreaks of spruce budworm (*Choristoneura fumiferana*), increased outbreaks of forest tent caterpillar (*Malacosoma disstria*) and jack pine budworm (*Choristoneura pinus pinus*), and a significant increase in the range of the gypsy moth (*Lymantria dispar*) (Volney and Fleming 2000, Lemprière et al. 2008).

Measurement variables include:

a) spread of fish- and waterborne diseases
b) frequency, intensity, and duration of insect outbreaks
c) distribution, duration, and rate of spread of parasitic plant/tree diseases
d) range expansion of wildlife diseases

Distribution of ecosystems

Over time, warming temperatures, changing precipitation patterns, and increased frequency of extreme events will contribute to the emergence of new ecosystems (Sukumar et al. 1995, IPCC 2007a, McKenney et al. 2010). Species often coexist because they coevolved in relatively stable climatic conditions. However, with rapid climate change it is likely that most species will respond in physiologically and/or behaviourally unique ways, potentially resulting in the decoupling of relationships and non-linear responses where some species remain and adapt while others migrate to more suitable bioclimates or disappear (Varrin et al. 2007, Nituch and Bowman 2013).

Table 3. *Climate change response indicators and proposed measurement variables for various ecosystem components (bold=indicator, plain text=measurement variable).*

Lakes and streams[1]	Terrestrial vegetation	Wetlands	Wildlife
Disease, parasite, and pest distribution -Spread of fish and waterborne diseases **Ecosystem productivity** - Secondary productivity **Ice cover** - Duration of ice cover - Maximum amount of ice that forms annually **Phenological events** - Timing of spawning by selected fish species - Timing of emergence by selected aquatic insects - Algal blooms **Species abundance** - Abundance of selected fish species **Species composition** - Composition of aquatic communities **Species distribution** - Distribution of selected fish species **Water quality** - Surface and profile summer water temperature in lakes, streams, and groundwater - Presence/absence of coldwater fish species in littoral areas in spring and summer - Proportion of large and small zooplankton - Water chemistry (e.g. pH, clarity, alkalinity, dissolved organic carbon, phosphorus and oxygen levels) - Abundance of species sensitive to oxygen depletion **Water quantity** - Changes in water levels of lakes - Changes in stream flow rates - Ground water - changes in water table	**Disease, parasite, and pest distribution** - Frequency, duration, and intensity of insect outbreaks - Distribution, duration, and rate of spread of parasitic plant/tree diseases **Distribution of ecosystems** - Diversity of vegetation classes on the landscape **Ecosystem productivity** - Changes in annual net primary productivity - Changes in tree growth **Phenological events** - Timing of leaf-out - Timing of flowering and senescence **Species abundance** - Abundance of selected terrestrial plant species **Species composition** - Composition of terrestrial plant communities **Species distribution** - Distribution of selected terrestrial plant species **Wildfires** - Average area burned per year - Length of the fire season - Fire severity - Fire distribution	**Coastal wetlands** - Extent of coastal wetlands - Water quality of Great Lakes coastal wetlands - Water quality of marine coastal wetlands **Distribution of ecosystems** - Distribution of wetland types on the landscape - Replacement of wetland ecosystem types - Permafrost thaw rates - Extent of permafrost lands **Ecosystem productivity** - Changes in net primary productivity **Permafrost** - Freeze and thaw dates in the area of discontinuous permafrost **Species distribution and composition** - Distribution of selected wetland plant and wildlife species - Invasive/exotic species - Composition of wetland plant communities **Water quantity** - Wetland water levels - Shoreline boundaries in wetlands **Wildfires** - Average area burned per year - Length of the fire season - Fire severity - Fire distribution	**Disease, parasite and pest distribution** - Range expansions of wildlife diseases **Habitat availability** - Ecosystem connectivity - Extent of key habitat types - Area of available habitat **Habitat quality** - Changes in the reproductive success of wildlife - Changes in survivorship **Phenological events** - Timing of breeding in selected mammal, bird, reptile, amphibian, and insect species - Timing of bird migration - Timing of spring emergence in selected mammal, reptile, amphibian, and insect species - Timing of emergence from dormancy in selected insect species **Species abundance** - Abundance of selected wildlife species **Species composition** - Composition of selected wildlife communities **Species distribution** - Range expansions of selected wildlife species - Range contractions of selected wildlife species - Shifts in winter ranges of selected wildlife species

[1]Habitat quality was not included as a key indicator of climate change or climate change effects in lakes and streams since the measures of this indicator can be derived from the water quality and quantity indicators.

Table 4. *Indicators of stress and mitigation and proposed measurement variables.*

	Indicator	Measurement variable
Stressor	Drought	- Trends in soil moisture
	Extreme weather events	- Changes in the frequency of rain storms - Changes in the severity of rain storms - Trends in wind events - Changes in the frequency of ice storms - Changes in the severity of ice storms
	Precipitation	- Trends in precipitation over time
	Snow cover	- Changes in the total area covered by snow - Changes in snow depth - Timing of spring melt
	Temperature	- Trends in air temperature over time - Trends in growing degree days - Trends in the frequency of extreme temperature events - Evapotranspiration
Mitigator	Carbon budgets in natural and managed ecosystems	- Trends in atmospheric/terrestrial greenhouse gas exchange - Changes in the amount of carbon stored in terrestrial and aquatic ecosystems - Net organic carbon - Net carbon source/sink

Ecosystem reconfiguration is occurring. Some boreal species have shifted their ranges northward (Bhatt et al. 2010; Chapin et al. 2005, 2010; Tape et al. 2006) and climate model-scenario projections suggest continued range shifts will occur with continued warming (Emanuel 1985, Liess et al 2012). At the southern edge of the boreal forest, warming temperatures may degrade boreal peatlands or cause them to disappear (Environment Canada 2004). Many wetlands in the north exist because of impeded drainage due to underlying permafrost (Rouse et al. 2003, McLaughlin and Webster 2013). Loss of permafrost will alter peatland hydrology, carbon storage, and greenhouse gas emissions (McLaughlin and Webster 2013)

Measurement variables include:

a) diversity of vegetation classes on the landscape
b) distribution of wetland types on the landscape
c) replacement of wetland ecosystem types
d) permafrost thaw rates
e) extent of permafrost lands

Ecosystem productivity

Warmer temperatures are expected to accelerate tree growth due to a longer growing season and a reduction in the frequency of summer frost events. Although forest productivity may increase under elevated carbon dioxide, moisture stress and/or nutrient availability may constrain productivity (Joyce and Nungesser 2000, Parker et al. 2012). Both primary and secondary production rates in lakes are expected to increase in response to warmer temperatures (Wrona et al. 2006), but increased summer temperatures could also reduce secondary productivity, particularly in lakes with a pronounced increase in thermal stratification (Minns et al. 2009).

Measurement variables include:

a) secondary productivity in aquatic ecosystems
b) net primary productivity in both terrestrial and wetland ecosystems
c) tree growth rate

Habitat availability

Globally, habitat loss has contributed to the decline of at least 85% of the amphibian, bird, and mammal species currently at risk of extinction (Baillie et al. 2004). While agriculture and urbanization are the most common causes of habitat loss, climate change is also modifying ecosystem structure and function (Coristine and Kerr 2011). For example, polar bears (*Ursus maritimus*) are among the most vulnerable species because of their dependence on sea ice for feeding, mating, and resting habitat (Durner et al. 2009, Abraham et al. 2011). The ice platform is disappearing; between 1971 and 2003 the length of the ice-free season in Hudson Bay and James Bay increased significantly (Gagnon and Gough 2005). In addition, duration of ice cover, snow depth, roughness of ice, and heavy spring rain events are implicated in declining body condition of southern (Obbard et al. 2006) and western (Stirling et al. 1999) Hudson Bay polar bear populations.

Measurement variables include:

a) ecosystem connectivity
b) extent of key habitat types
c) area of available habitat

Habitat quality

Access to quality food is important for species survival and reproduction. For example, the blueberry (*Vaccinium* spp.) is an important staple for the black bear (*Ursus americanus*). With increased frequency of drought, blueberry production will vary and affect black bear populations. For example, following a berry crop failure, the survival of first year cubs is jeopardized and female bears produce fewer cubs the following year (Landriault et al. 2000). In addition, berry crop failure can result in increased human-bear conflicts (Rogers 1976), which adds to bear mortality.

Measurement variables include:

a) reproductive success of wildlife
b) survivorship

Ice cover

The presence and absence of ice affects the heating and cooling of the Earth's surface and the distribution and abundance of seasonal habitat. For example, later freeze-up and earlier break-up can alter the timing of fish spawning and affect food supply (Ontario Biodiversity Council 2010). The duration of lake ice cover in the Northern Hemisphere has declined significantly in recent decades, and climate model-scenario projections suggest that this trend will continue (Magnuson et al. 2000, Futter 2003, Duguay et al. 2006, Minns et al. 2012).

Measurement variables include:

a) duration of ice cover on lakes
b) maximum amount of ice that forms annually on lakes

Permafrost

Mean annual air temperature controls permafrost occurrence at biospheric scales, but snowfall, peatland area, and vegetation structure affect the distribution and type of permafrost at local-regional levels (McLaughlin and Webster 2013). And although variable, warmer soil temperatures and associated higher thawing rates will reduce the extent of permafrost in Ontario's Far North[1] (McLaughlin and Webster 2013). Permafrost loss will in turn affect habitat (e.g., vegetation composition and structure) of aquatic and terrestrial species and ecosystem function (e.g., the hydrological cycle and the flow of carbon and methane) (Smith and Brown 2009). An important interface is the active layer that alternates between winter freezing and summer thawing (Hinzman et al. 1991).

Measurement variables include:

a) freeze and thaw dates in the area of discontinuous permafrost

Phenological events

Life cycle events (phenology) are affected by climate, elevation, and other characteristics that combine to create habitat. Climate change is significantly altering phenological patterns in species around the world (Parmesan 2006, Varrin et al. 2007, Nituch and Bowman 2013, Nantel et al. in prep.). For example, walleye (*Sander vitreus*) are spawning earlier (Schneider et al. 2010), birds are occupying breeding habitat and producing young earlier (Cotton 2003, Waite and Strickland 2006, Hurlbert and Liang 2012), amphibians have increased the breadth of their breeding season (Walpole and Bowman 2011), and the earlier onset of the growing period at medium and high latitudes has resulted in earlier leaf-out and flowering (Schwartz et al. 2006). Since phenological events are closely linked to climate, the timing of these events can serve as useful indicators of climate change (US EPA 2010).

Measurement variables include;

a) timing of spawning in selected fish species
b) timing of emergence of selected aquatic insect species
c) algal blooms
d) timing of leaf-out
e) timing of flowering and senescence
f) timing of bird migration
g) timing of breeding in selected insects, amphibians, reptiles, birds, and mammals
h) timing of spring emergence (adults) of selected insects, amphibians, reptiles, and mammals
i) timing of emergence from dormancy of selected insect species (e.g., butterflies, dragonflies, and damselflies)

Species composition, distribution, and abundance

Species composition, distribution, and abundance data are often used to assess ecosystem structure. Since these indicators are intricately linked (i.e., changes in species abundance and distribution alter species assemblages; Bradford and Warren 2012) they are grouped and assessed together.

[1] Ontario's Far North spans the width of Ontario, from Manitoba in the west to James Bay and Quebec in the east. It covers more than 40 % of the province's area, about 450 000 km^2. It contains the entire Ontario portion of the Hudson Plains Ecozone, and stretches south to the boreal forests in Ontario's mid-latitudes.

Aquatic ecosystems

As water temperatures rise, habitat for warmwater species such as smallmouth bass (*Micropterus dolomieui*) and coolwater species such as walleye (*Stizostedion vitreum*) will increase (Shuter et al. 2002, Kling et al. 2003, Chu et al. 2005, Chu and Fischer 2012). Conversely, available habitat for coldwater species such as lake trout (*Salvelinus namaycush*) and brook trout (*Salvelinus fontinalis*) will decrease (Kling et al. 2003, Chu et al. 2005, Minns et al. 2009). Aggressive predators such as bass and other warmwater fish disrupt foodwebs and outcompete native species. For example, the expansion of smallmouth bass into northern Ontario could lead to the localized extinction of thousands of populations of northern redbelly dace (*Phoxinus eos*), finescale dace (*Phoxinus neogaeus*), fathead minnow (*Pimephales promelas*), and pearl dace (*Margariscus margarita*) (Jackson and Mandrak 2002). This level of extirpation could, in turn, negatively affect indigenous predators such as lake trout (Vander Zanden et al. 2004).

Measurement variables include:

a) abundance and distribution of selected fish species
b) distribution of selected wetland plant and wildlife species
c) composition of aquatic communities
d) composition of wetland plant communities
e) presence/absence of naturally invasive North American species in aquatic habitats
f) presence/absence of invasive exotic species in aquatic habitats

Terrestrial ecosystems

Like aquatic ecosystems, shifts in species distribution in response to physiological thresholds, species relationships, and habitat availability will have some of the most modifying effects on ecosystem composition, structure, and function. Although many species will occupy niche space north of their current ranges (see Thomas and Lennon 1999, Malcolm et al. 2002, Root and Schneider 2002, Crozier 2004, Root and Hughes 2005, Hitch and Leberg 2007, McKenney et al. 2007, Johnston et al. 2009, Parker et al. 2012), migration response and success will be ecosystem/habitat-specific resulting in a temporal-spatial patchwork of increasing and decreasing species richness across the province (Nantel et al. in prep.).

Measurement variables include:

a) abundance and distribution of selected terrestrial plant species
b) abundance and range expansions/contractions of selected wildlife species
c) shifts in winter ranges of selected wildlife species
d) composition of terrestrial plant communities
e) presence/absence of invasive exotic species in terrestrial habitats
f) composition of wildlife communities

Water quality

Water quality is critical to Ontario's long-term ecological, economic, and social health. Water temperature results from heat exchange with the atmosphere (Lyche-Solheim 2010) and therefore increased air temperature will increase water temperature. Increased water temperature affects aquatic ecosystem structure and function through many pathways (Wrona et al. 2006) with various effects, including increased risk of oxygen depletion, more frequent algal blooms, loss of coldwater aquatic species habitat, and range expansion of invasive species.

Measurement variables include:

a) surface and profile summer water temperature in lakes, streams, and groundwater
b) presence/absence of coldwater, coolwater, and warmwater fish species in littoral areas in spring and summer
c) proportions of large and small zooplankton

d) water chemistry, e.g., pH, clarity, alkalinity, dissolved organic carbon, phosphorus, oxygen levels
e) abundance of species sensitive to oxygen depletion

Water quantity

Water volume in lakes, rivers, and wetlands is a balance between water entering the system as rain, snowfall, and runoff and water leaving the system through evaporation and withdrawal. In lakes not affected by excessive withdrawal, water levels are predominantly driven by climate conditions (Vuglinskiy 2009). For example, in the Great Lakes basin, total annual runoff is projected to decrease as temperatures warm; flows are projected to increase in winter and decrease in summer (Mortsch et al. 2000, Cunderlink and Simonovic 2005, de Loë and Berg 2006). Water quantity will also be affected by decreasing groundwater recharge rates and changes in the amount and timing of groundwater flow into lakes, streams, and wetlands (de Loë and Berg 2006). In some parts of southern Ontario[2] seasonal water shortages already occur (de Loë et al. 2001, Ivey 2001).

Measurement variables include:

a) lake water levels
b) wetlands water levels
c) shoreline boundaries in wetlands
d) stream flow rates
e) water table levels

Wildfires

Increased risk of wildfire has significant implications for ecosystem function and human health and well-being. The area burned by wildfires in Canada has risen dramatically since 1970; summer temperatures have also risen during this time (Karsh and MacIver 2010). Rising temperatures and more frequent dry periods will increase the frequency and severity of wildfires and the area burned in Ontario (Flannigan et al. 1998, Stocks et al. 1998, Wotton et al. 2005, Stocks and Ward 2011).

Measurement variables in terrestrial and wetland ecosystems include:

a) average area burned per year
b) length of the fire season
c) fire severity
d) fire distribution

3.2 Stressor indicators

Drought

Globally, the area affected by drought has increased since the 1970s, likely a result of climate change (IPCC 2007b). As temperatures increase and remain warmer for longer periods, droughts are projected to occur more frequently and last longer in Ontario (EBNFLO Environmental AquaResource Inc. 2010). Extended periods of drought could result in low flows in streams, rivers, and lakes (EBNFLO Environmental AquaResource Inc. 2010). Drought also contributes to the degradation of water quality, increased frequency and size of wildfires, and increased susceptibility to insect infestations and plant diseases (OMNR 2010a).

Measurement variables include:

a) soil moisture

[2] Southern Ontario is the portion of Ontario south of the Area of the Undertaking. It includes the entire Ontario portion of the Mixedwood Plains Ecozone.

Extreme weather events

Extreme weather events include flooding, drought, heat waves, ice storms, lightning activity, and wind storms. Recent events in Ontario such as flooding highlight the vulnerability of ecological-social systems to climate change (Cheng et al. 2005, Hengeveld and Whitewood 2005, Chiotti and Lavender 2008, Stocks and Ward 2011). Climate model-scenarios suggest that the effects of extreme weather events will increase (e.g., Stocks and Ward 2011, Waller et al. 2012).

Measurement variables include

a) rain storm frequency
b) ain storm severity
c) wind events
d) ice storm frequency
e) ice storm severity

Precipitation

As annual temperatures warm, annual and seasonal precipitation patterns will grow more variable (IPCC 2007a). For example, climate-model scenarios project that precipitation in Ontario will increase in winter and spring, remain unchanged in fall, and decrease in summer in the south and central part of the province (Colombo et al., in prep.). Given that water is a critical part of habitat, precipitation patterns will significantly affect the distribution and abundance of species throughout Ontario. For example, since many amphibian species rely on vernal pools as breeding habitat, any reduction or change in precipitation could cause a decline in amphibian populations (Blaustein et al. 2010).

Measurement Variables

a) change in seasonal precipitation patterns

Snow cover

Snow cover is affected by climate change and influences climate since snow reflects energy away from the Earth's surface. Warmer temperatures are expected to reduce the amount of snowfall, which could lead to further climate warming through positive feedback from more exposed ground and longer open water periods. Snow cover is important for many plant and wildlife species. Some plants require a protective layer of snow to insulate them from cold winter temperatures, while fish and wildlife rely on snowmelt to replenish ground and surface water (U.S. EPA 2010). Conversely, increased snowfall can adversely affect the survival of species such as white-tailed deer (*Odocoileus virginianus*) (Garroway and Broders 2007).

Measurement variables include:

a) changes in total area covered by snow annually
b) snow depth
c) timing of spring melt

Temperature

As a physical measure of the local thermal energy of matter or radiation, temperature provides an indication of hotness and coldness on a measureable scale. Temperature is a critical determinant in the formation of habitat. For example, changes in air temperature cause changes in water surface temperatures, precipitation patterns, and other climate variables (IPCC 2007a). Between 1948 and 2008, the average annual temperature in Ontario increased by 1.4 °C (Government of Ontario 2011), and scientists project that by 2050, annual average temperatures in Ontario will be 2.5 to 3.7 °C higher than the 1961 and 1990 baseline (Expert Panel on Climate Change Adaptation 2009).

Measurement variables include:

a) air temperature over time
b) growing degree days
c) frequency of extreme temperature events
d) evapotranspiration

3.3 Mitigation indicators

Carbon budgets in Natural and Managed Ecosystems

The carbon cycle, hydrological cycle, nitrogen cycle, and other cycles collectively and synergistically function to support life on Earth. Since people are now releasing huge carbon reserves that have not been part of the biosphere for millions of years, the dynamics of current ecological cycles are changing as more of this ancient carbon is added to the atmosphere.

The Government of Ontario is committed to reducing carbon and other greenhouse gas emissions and effectively managing sequestered carbon. Ontario's ecosystems store large volumes of carbon in the soil and as biomass. For example, Ontario's managed forests and wood products currently store about 6.4 gigatonnes of carbon (Colombo et al. 2007, Chen et al. 2010, Ter-Mikaelian et al. 2013) and peatlands in the Far North store about 36 gigatonnes of carbon as peat (Far North Science Advisory Panel 2010), which is about 25% of the carbon stored in Canada's peatlands (McLaughlin and Webster 2013). Knowledge about the flow of carbon through complex social-ecological systems is important and difficult to predict because of the uncertainty around future human-induced greenhouse gas emissions.

Measurement variables include:

a) atmospheric/terrestrial greenhouse gas exchange
b) amount of carbon stored in terrestrial and aquatic ecosystems
c) amount of net organic carbon
d) net carbon source/sink

4.0 Indicators Addressed by Ongoing Monitoring Programs

Eleven monitoring programs produce data relevant to at least one climate change response indicator. Monitoring programs support more indicators for lakes/streams and terrestrial vegetation themes than wetlands and wildlife themes (Table 5). Climate change-related wildlife monitoring is limited and MNR does not sponsor wetland monitoring programs.

Table 5. *The relationship between long-term monitoring programs sponsored by the Ontario Ministry of Natural and climate change monitoring needs (response indicators) for various ecosystem components: aaMNR monitoring programs support all measurement variables of the indicator; aMNR monitoring programs support most measurement variables of the indicator; x MNR monitoring programs do not support measurement of the indicator).*

Lakes and stream	Terrestrial vegetation	Wetlands	Wildlife*
Disease, parasite and pest distribution x	Disease, parasite and pest distribution ✔	Coastal wetlands x	Disease, parasite and pest distribution x
Ecosystem productivity* ✔ ✔	Distribution of ecosystems ✔	Distribution of ecosystems x	Habitat quality x
Ice cover x	Ecosystem productivity ✔	Ecosystem productivity x	Phenological events x
Phenological events x	Phenological events x	Permafrost x	Species abundance ✔ ✔
Species abundance* ✔ ✔	Species abundance ✔ ✔	Species distribution and composition x	Species composition x
Species distribution* ✔ ✔	Species distribution ✔ ✔	Water quantity x	Species distribution ✔ ✔
Species composition* ✔	Species composition ✔ ✔	Wildfires x	
Water quality* ✔	Wildfires ✔		
Water quantity ✔ ✔			

*Applies to lakes only.

4.1 Lakes and streams

Two MNR programs support lakes and streams indicators: the Broadscale Inland Lakes Monitoring Program and the Surface Water Monitoring Network. The data collected inform six indicators: ecosystem productivity, species abundance, species composition, species distribution, water quality, and water quantity (Table 6). MNR does not currently support long-term monitoring programs for ice cover.

4.1.1. Broadscale Inland Lakes Monitoring Program

The Broadscale Inland Lakes Monitoring Program was designed to monitor the health of Ontario's lakes over time, increase biologists' understanding of the state of fish and other aquatic resources, identify stresses on these resources, and report on change. Initiated in 2008, the purpose of the program is to collect data on several lakes in each of the province's Fisheries Management Zones[3]. Water quality (including temperature and oxygen), fish community composition, sport fish abundance, and invasive species information is are collected at regular intervals.

Monitoring is based on four core components: target fish populations, fish habitat, aquatic communities, and exploitation of target fish species. Summer index netting is conducted to collect abundance and biological data on the harvested fish species and the rest of the fish community, including zooplankton. Some limnological variables such as lake bathymetry, water temperature, and oxygen levels, are surveyed during the netting program. Other measures of

Table 6. *Lake and stream indicators supported by long-term monitoring programs sponsored by the Ontario Ministry of Natural Resources.*

Indicator	Measurement variable(s)	Broadscale inland lakes monitoring	Surface water monitoring
Ecosystem productivity*	Biomass turnover	✔	
	Aging of some fish species	✔	
	Growth of some fish species	✔	
Species abundance*	Abundance of some fish species	✔	
Species composition*	Changes in fish and zooplankton community composition	✔	
Species distribution*	Species range and shifts	✔	
Water quality	Summer water temperature	✔	
	Water clarity	✔	
	Alkalinity	✔	
	pH	✔	
	Dissolved organic carbon (DOC)	✔	
	Phosphorus	✔	
	Oxygen profiles	✔	
	Presence/absence of zooplankton and coldwater fish species in littoral zones	✔	
	Surface water temperature		✔
Water quantity			✔

*Currently monitored in lakes only

[3] For recreational fishing purposes Ontario is divided into 20 Fisheries Management Zones. Detailed maps of the zone boundaries can be found in the 2014 Ontario Recreational Fishing Regulations Summary (Fish and Wildlife Services Branch, OMNR 2013).

water quality, including water clarity and water chemistry, are collected during the spring. Aerial surveys are used to estimate angling effort throughout the fishing season.

4.1.2. Surface Water Monitoring Network

MNR uses the Surface Water Monitoring Network to collect and analyze data on water flows and water levels in lakes and rivers across Ontario. In addition, some climate data such as air and surface water temperatures and precipitation are collected.

A network of stream gauge stations has been established in lakes and rivers to collect water level and flow data, and climatic data are collected at weather stations across the province. Water flow, water level, and climate data are recorded several times daily and aggregated into daily, monthly, and yearly maximums, minimums, and averages. The length of time over which data have been collected varies but in some locations it is over 100 years.

4.1.3. Considerations

Sampling densities are higher in areas with large human populations than in rural or remote areas. For example, few water monitoring stations exist in the Far North, and most of the data sets have not been updated for more than 30 years (Far North Science Advisory Panel 2010). Installation of new stream gauge stations in the Far North is a current MNR priority. In addition, the Broadscale Inland Lakes Monitoring Program will be expanded to include the Far North.

The MNR is collecting more data on water quality in lakes than in stream/river systems. At present, a monitoring system is not in place for the collection of data on the following indicators in stream/river ecosystems: ecosystem productivity, species abundance, species composition species distribution, and water quality. The MNR has developed a standardized Ontario Stream Assessment Protocol that includes these indicators, which is being used by Conservation Authorities to collect data in some watersheds.

4.2 Terrestrial vegetation

Three long-term monitoring programs support data collection on several terrestrial vegetation indicators and one stressor indicator: the Forest Health Monitoring Program, the National Forest Inventory, and the Growth and Yield Program. The data collected by these programs align with five of eight terrestrial vegetation indicators: ecosystem productivity, species abundance, species composition, species distribution, and disease distribution (Table 7). None of MNR's long-term monitoring programs collect information on the phenology of trees and other plants or shifting ecosystem boundaries.

Table 7. *Terrestrial vegetation indicators supported by long-term monitoring programs sponsored by the Ontario Ministry of Natural Resources.*

Indicator	Program measurement variable(s)	Forest health monitoring	Provincial growth and yield	National forest inventory
Disease, parasite and pest distribution	Frequency, duration, and intensity of insect outbreaks	✔		
Ecosystem productivity	Tree growth		✔	✔
Extreme weather events	Severe wind, ice storms, etc.	✔		
Species abundance	Tree, shrub, and herb abundance		✔	✔
Species composition	Tree, shrub, and herb composition		✔	✔
Species distribution	Tree, shrub, and herb distribution			✔

4.2.1. Forest Health Monitoring Program

Monitoring the health of Ontario's forest has been a joint effort by the governments of Canada and Ontario over the past 40 years. MNR now has the responsibility to monitor the occurrence of native and invasive species (e.g., insect and disease) and abiotic (e.g., severe weather) disturbances and events. The program is based on a system of permanent sample plots, temporary sample plots, plantation surveys, and aerial mapping of major forest disturbances. Data are used to report on the health of Ontario's forests and aid in the development of forest pest management plans and policies.

4.2.2. National Forest Inventory (NFI)

Initiated in 1997, Canada's NFI is used to monitor a network of sampling sites covering 1% of the country's land mass on a ten year re-measurement cycle. Sample points provide data on the state of Canada's forests and change over time. The NFI data are used to inform forest policy, support science projects, and meet regional, national, and international reporting commitments. Canada's federal, provincial, and territorial governments have collaboratively developed standards and procedures for data collection. Provincial and territorial governments are responsible for data collection and the federal government sponsors data management, analysis, and report writing. There are 2 600 plots located on a systematic grid across Ontario. A combination of aerial and ground plots provide data on the origin and composition, volume and biomass of tree, shrub, and herb species, as well as woody debris. Soil properties are also sampled.

4.2.3. Growth and Yield Program

Established in 1991, Ontario's Growth and Yield Program acquires and disseminates data about the growth, productivity, and dynamics of Ontario's forests. Through a network of approximately 1 100 permanent sample plots (Sharma et al. 2008), forest floor, tree site characteristics, understory vegetation, and downed woody debris data are collected. Data are used to create yield curves to predict stand volume over time, and create or calibrate growth and yield models. Data collection methods are standardized and used by government and industry.

4.2.4. Considerations

Inventory initiatives such as the Forest Resource Inventory (FRI) and the Provincial Satellite-derived Disturbance Mapping provide point-in-time data that could improve understanding of climate change effects on terrestrial vegetation. The FRI is an extensive survey that characterizes forest (at a 1:20 000 scale) in terms of tree species, conditions, and regeneration. The MNR recently redesigned the FRI to include an ecological land classification component that captures data on ecological function of all types of terrestrial ecosystems. It also includes data collected in permanent sample plots. The enhanced FRI covers the Area of the Undertaking (AOU)[4], but not southern Ontario or the Far North. The MNR is undertaking Provincial Satellite-derived Disturbance Mapping in conjunction with other inventory and mapping initiatives. Disturbances to land cover occur constantly, and the classification of medium spatial resolution (30 m) satellite imagery is a cost-effective and repeatable mechanism for mapping these changes. Change events such as forest depletion due to natural or anthropogenic stresses and subsequent regeneration are defined in the mapping process. Disturbance mapping is currently focused on three years: 1990, 2000, and 2009. Thus, it could provide information to describe the state of the distribution of ecosystems and wildfires at specific points in time.

Other terrestrial vegetation inventory and mapping initiatives such as the Far North Land Cover Project and the Provincial Land Cover and Southern Ontario Land Resources Information System (SOLRIS) provide point-in-time data on the spatial distribution of some vegetation types in the province. In addition, in southern Ontario the MNR and various conservation partners use the vegetation sampling protocol (VSP) to collect data on a variety of vegetation classes (e.g., wetlands, grasslands, forests, and disturbed vegetation). Initial VSP sampling was completed from 2005 to 2008. Although there is no commitment to revisit plots on a regular basis, data collected could be used to inform the state of species abundance, species composition, and species distribution indicators at specific points-in-time.

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4 An area of approximately 43.8 million hectares of which 27.1 million hectares is Crown forest, on which forest management activities are conducted. It encompasses parts of Ontario's Boreal and Great Lakes – St. Lawrence forests. A map showing the boundaries of the Area of the Undertaking is available on the Ontario's Forests website.

A few programs within MNR capture phenological data on an ad-hoc basis. For example, under the auspices of the Forest Health Monitoring Program, dates of leaf out, flowering, and senescence are occasionally recorded. In addition, some phenological data for rare plant species and/or communities are collected and stored in the Natural Heritage Information Centre (NHIC) database.

Table 8. *Wildlife indicators supported by long-term monitoring programs sponsored by the Ontario Ministry of Natural Resources.*

Indicator	Program Measurement variable(s)	Climate change and terrestrial biodiversity	Songbird migration monitoring (Long Point and Thunder Cape)	Moose aerial inventory	Multi-species invention and monitoring	Nocturnal owl Survey	Snowshoe hare population assessment
Habitat availability	Proportion of monitoring plots with habitat				✔		
	Amount of habitat at each monitoring plot				✔		
Habitat quality	Repeated estimates through time of calf recruitment (calves per 100 cows) for Wildlife Management Units			✔			
	Repeated measures through time for moose population density			✔			
Species abundance	Abundance of northern and southern flying squirrel species	✔					
	Relative abundance indices for multiple species of migratory birds; surveys repeated annually		✔				
	Total projected moose abundance by Wildlife Management Unit			✔			
	Relative abundance indices for multiple species of small mammals, red-backed salamanders and forest songbirds				✔		
	Relative abundance indices for multiple species of owls; surveys repeated annually					✔	
	Snowshoe hare pellet density						✔
Species composition	Migratory birds identified to species		✔				
	Small mammals, forest songbirds, salamanders and medium to large mammals identified to species				✔		
	Owls identified to species					✔	
Species distribution	Range expansion of southern flying squirrel	✔					
	Range contraction of northern flying squirrel	✔					
	Changes in spatial extent of range or spatial patterns in density can be calculated by pooling multiple years of data			✔			
	Probability of occupancy for multiple species of small mammals, red-backed salamanders, forest songbirds and medium to large mammals; repeated measures through time allow tracking of change in range extent				✔		
	Changes in the distributions of owl species can be measured since the survey design is spatially extensive; limited coverage in northern Ontario					✔	

4.3 Wetlands

No trend data are available for the wetland indicators. However, MNR sponsors ongoing inventory programs that provide point-in-time indicators that could support wetland indicators. These programs include the FRI, the Far North Plot Reference Database, the Far North Land Cover Project, and SOLRIS. The ecological land classification component of the enhanced FRI provides information on the distribution of wetlands and the area of land covered by wetlands in the AOU.

The Far North Plot Reference Database (from about 1978) and the Far North Land Cover Project (2008) contains point-in-time information on wetlands in the Far North. SOLRIS provides point-in-time information on wetlands on crown and private land in southern Ontario. If updated, these data sets could be used to assess the state of some of the wetland indicators at different points in time.

4.4 Wildlife

Six long-term monitoring programs inform wildlife indicators: the Climate Change and Terrestrial Biodiversity Program, the Snowshoe Hare Population Assessment Program, migration monitoring (Long Point and Thunder Cape), the Moose Aerial Inventory, the Multi-species Inventory and Monitoring (MSIM), and nocturnal owl surveys. The latter four programs are part of the Provincial Wildlife Population Monitoring Program (PWPMP) (OMNR 2010b). Information collected through these programs aligns with habitat availability, habitat quality, species abundance, species composition, and species distribution indicators (Table 8). Currently none of MNR's wildlife monitoring programs provide data on the phenology or distribution of parasites and diseases.

4.4.1. Climate Change and Terrestrial Biodiversity Program

The objectives of this program are to improve the MNR's understanding of the consequences of climate-induced range expansion of northern and southern flying squirrels (*Glaucomys sabrinus* and *G. volans*), and improve understanding about how biodiversity is affected by such changes (e.g., hybridization).

4.4.2. Snowshoe Hare Population Assessment Program

The snowshoe hare (*Lepus americanus*) is a keystone species and population fluctuations significantly affect other species such as lynx (*Lynx americanus*). MNR employs pellet density measures to assess snowshoe hare population trends and determine whether populations in boreal and temperate forest habitats are equally cyclic (i.e., across the species' southern range boundary).

4.4.3. Provincial Wildlife Population Monitoring Program (PWPMP)

The PWPMP collects status and trend information for terrestrial wildlife populations inhabiting Ontario's managed forests through programs such as bird migration monitoring conducted at Thunder Cape and Long Point bird observatories (partnership with Bird Studies Canada), nocturnal owl surveys, and moose aerial inventories. The PWPMP is also implementing a field-based MSIM approach to acquire population information for terrestrial vertebrate species. The purpose of MSIM is to provide population data (presence and/or relative abundance) and associated habitat condition data for a large number of wildlife species over a broad scale in both time and space using a consistent set of protocols. The MSIM is in the early stages of implementation. It will capture data to support the habitat availability indicators (at permanent monitoring sites), and the abundance, composition and distribution indicators. The core survey protocols include presence-absence of medium to large mammals, relative abundance of forest birds, calling amphibians, salamanders, and small mammals.

4.4.4. Considerations

Several data sets provide point-in-time information. For example, the NHIC database and the Ontario Odonata Atlas provide data on species abundance, distribution, and composition. Information gathered through research programs such as the small mammal survey in Algonquin Park could also support wildlife indicators. In addition, data collected by partner agencies that are useful in detecting the effects of climate change include the Ontario Breeding Bird Atlas (Bird Studies Canada), the Atlas of the Mammals of Ontario (Ontario Nature), the Ontario Amphibian and Reptile Atlas (Ontario Nature), and the Ontario Butterfly Atlas (Toronto Entomologists' Association).

Indicator species such as the boreal chickadee (*Poecile hudsonica*), eastern red-backed salamander (*Plethodon cinereus*), northern flying squirrel, southern flying squirrel, spring butterfly species (e.g., *Celastrina ladon*, *Callophrys niphon*, *Euchloe Olympia*), and Odonates such as *Epitheca spp.* have been identified. More work is needed to determine whether changes in their biology and ecology (such as abundance, distribution, and timing of phenological events) are useful indicators of climate change.

Table 9. *Relationships among local (Lake Simcoe), provincial (Ontario Ministry of Natural Resources – MNR), national Canadian Council of Ministers of the Environment – CCME), and international (Intergovernmental Panel on Climate Change – IPCC) climate change indicators.*

MNR indicator		Lake Simcoe indicator (SSIS 2011)	CCME climate change indicators initiative (CCITG of the CCME 2003)	IPCC indicator (IPCC 2007a)
Response indicators	Coastal wetlands			
	Disease distribution			
	Distribution of ecosystems	Yes		
	Ecosystem productivity			
	Habitat availability		Yes (polar bear)	
	Habitat quality			
	Ice cover		Yes	Yes
	Permafrost			Yes
	Phenological events	Yes (plants only)	Yes (plants only)	Yes
	Species abundance	Yes	Yes	Yes
	Species composition	Yes	Yes	
	Species distribution	Yes	Yes	Yes
	Water quality	Yes		Yes
	Water quantity	Yes	Yes	Yes
	Wildfires			
Stressor and mitigation indictors	Drought	Yes	Yes	Yes
	Extreme weather events		Yes	
	Precipitation	Yes		Yes
	Snow cover			Yes
	Temperature	Yes		Yes
	Ecosystem carbon budgets in managed and unmanaged ecosystems			

5.0 Discussion, Recommendations and Next Steps

Several MNR monitoring programs provide data on climate change and climate change effects on natural resources. However, gaps do exist, particularly for wetlands and wildlife. And while MNR might be able to address some of these gaps with inventory program data collected under the auspices of the enhanced FRI, the Far North Land Cover Project, and SOLRIS, or by using data compiled by other agencies, new monitoring programs will be needed to effectively detect the response of Ontario's ecosystems to climate change. A list of MNR and other data sets and monitoring programs outside MNR that could provide useful data is provided in Appendix I.

5.1 Stressor and mitigation indicators

The MNR is not responsible for monitoring some of the stressor indicators identified in this study. For example, precipitation, temperature, and extreme weather events are monitored by the Ontario Ministry of the Environment and Environment Canada. The MNR has collected snow cover and winter severity information on an ongoing basis via the Snow Network for Ontario Wildlife.

5.2 Linkages with other indicator processes

Climate change indicators identified in this study appear to be consistent with local, national, and international indicators (Table 9). They also align well with other MNR business needs:

- Ten indicators identified in this study have also been identified as key biodiversity indicators: coastal wetlands (combined with other wetlands in the analysis to inform a single indicator), distribution of ecosystems, habitat availability, habitat quality, species abundance, species composition, species distribution, water quality, water quantity, and drought.
- Eight indicators identified in this study are also used to report on the state of Ontario's forests: disease distribution, distribution of ecosystems, ecosystem productivity, habitat availability, species abundance, species distribution, wildfires, and ecosystem carbon budgets in managed and unmanaged ecosystems.

5.3 Recommendations

Although several existing monitoring programs align well with the identified climate change indicators, for some ecosystem components monitoring programs are either lacking or could be improved to help practitioners manage natural resources in light of the expected effects of climate change:

- Streams and river systems: An assessment protocol has been developed, but no provincial monitoring program has been implemented.
- Wildlife: Species-specific programs exist. MNR has developed and is in the early stages of implementing protocols for a broadscale monitoring program that will collect data on the presence/absence of key wildlife species and changes in habitat quantity and availability. Although the Multi-species Inventory and Monitoring Program of the Provincial Wildlife Population Wildlife Monitoring Program is expected to improve geographic and species coverage for monitoring wildlife population trends in managed forests, gaps in species coverage include reptiles, bats, and many other species or groups that may be rare or difficult to detect using existing survey protocols.
- Wetlands: Several inventory programs document the status of wetlands. To identify changes through time in the AOU, the MNR could use the enhanced FRI. In southern Ontario and the Far North, disturbance mapping provides a partial update to the land cover products. A full update of the entire area on a regular cycle would allow practitioners to monitor changes in wetlands over time.
- Limitations of indicators: Limited data are available for some of the indicators, including ice cover; the distribution of diseases, parasites, and pests; and phenological events. This study did not include an

assessment of how these limitations might affect the MNR’s ability to understand climate change and its effects on natural resources.

Recommendations from the study are:

1. Integrate climate change indicators and reporting requirements into existing monitoring programs, with an initial focus on the six provincial programs: broadscale inland lakes monitoring, surface water monitoring network, forest health monitoring, forest growth and yield, the provincial component of the National Forest Inventory, and multi-species inventory and monitoring.
2. Advance efforts on an integrated monitoring framework that includes climate change indicators and reporting.

Recommended next steps include:

- Identify desirable/attainable monitoring attributes for each measurement variable (e.g., population of interest, area of interest, and sampling unit). See Appendix II for a complete list of monitoring attributes and definitions.
- Identify suitable indicator species where applicable.
- Undertake trend analyses of indicators for which long-term data are available. Describe cause-effect relationships between climate change and ecosystem change.
- Scope potential socio-economic indicators and explore the idea of applying a socio-economic lens to communicate the results of trend analyses.
- Review external inventory and monitoring programs to determine which ones provide information that is relevant to the indicators identified in this report.
- Explore opportunities for multiple agency collaborative monitoring programs.

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Appendix I: Data sets (MNR and other) and monitoring programs outside MNR that may provide climate change information for Ontario

Ecosystem component	MNR data sets	Other data sets and monitoring programs
Lakes and streams	littoral zone studies long-term data from Lake Simcoe Ontario Stream Assessment Protocol	Canadian Ice Service Seasonal Summaries for the Great Lakes (Environment Canada) Experimental Lakes Area - Long-term Monitoring (Department of Fisheries and Oceans Canada) Great Lakes water levels (Department of Fisheries and Oceans Canada; National Oceanic and Atmospheric Administration) IceWatch*(Environment Canada and Nature Canada) Lake Partner Program (Ontario Ministry of the Environment) Ontario Benthos Biomonitoring Network (Ontario Ministry of the Environment) Provincial Water Quality Monitoring Network (Ontario Ministry of the Environment) Watershed Report Cards (Conservation Ontario) Water Survey of Canada (Environment Canada) Invasives Tracking System (Ontario Federation of Angler's and Hunters)
Terrestrial vegetation	- Ecological Land Classification plot data network - Far North Land Cover Project - NHIC rare species, wildlife concentration area, and plant community occurrence database - Ontario Niagara Escarpment Monitoring Program - Provincial Land Cover - Southern Ontario Land Resource Information System - Vegetation Sampling Protocol plot data network	- Climate Change Impacts on the Productivity and Health of Aspen (Canadian Forest Service) - Long Point Biosphere Reserve Monitoring Program (Long Point World Biosphere Reserve Foundation) - National Forestry Database (Canadian Council of Forest Ministers) - Ontario Forest Biomonitoring Network (Ontario Ministry of the Environment) - Nieghbourwoods* (University of Toronto) - Plant Hardiness Zone Atlas (Natural Resources Canada) - PlantWatch* (Environment Canada and Nature Canada) - Sugar Maple Plots (Ontario Ministry of the Environment) - Invasives Tracking System (Ontario Federation of Angler's and Hunters)
Wetlands	- ELC plot data network - Far North Land Cover Project - Ontario Far North Historical Plot Reference Database - Southern Ontario Land Resource Information System	- Canadian Wetland Inventory (Environment Canada, Canadian Space Agency, Ducks Unlimited Canada and the North American Wetlands Conservation Council) - Southern Ontario Wetland Conversion Analysis (Duck Unlimited Canada)

Ecosystem component	MNR data sets	Other data sets and monitoring programs
Wildlife	- NHIC rare species, wildlife concentration area, and plant community occurrence database - Atlas of Ontario Odonata - Ontario Herpetofaunal Summary Atlas - Snow geese surveys - Snow Network for Ontario Wildlife	- Amphibian Road Call Count *(Environment Canada) - Atlas of the Breeding Birds of Ontario* (Bird Studies Canada, Environment Canada, Ontario Nature, OMNR) - Atlas of the Mammals of Ontario (Ontario Nature) - Backyard Frog Survey (Environment Canada)* (Bird Studies Canada) - Canadian Lakes Loon Survey* (Bird Studies Canada) - Canadian Migration Monitoring Network* (Bird Studies Canada) - Christmas Bird Count* (Bird Studies Canada and Audubon) - Forest Bird Monitoring Program (Environment Canada) - FrogWatch* (Environment Canada and Nature Canada) - Great Lakes Marsh Monitoring Program* (Bird Studies Canada) - Long Point Biosphere Reserve Monitoring Program (Long Point World Biosphere Reserve Foundation) - Nocturnal Owl Monitoring Survey* (Bird Studies Canada) - Ontario Amphibian and Reptile Atlas (Ontario Nature) - Ontario Bank Swallow Project* (Bird Studies Canada) - Ontario Butterfly Atlas (Toronto Entomologists' Association) - Ontario Frog Call Survey* (Toronto Zoo) - Project Feeder Watch* (Bird Studies Canada) - Project Nest Watch* (Bird Studies Canada) - Ontario SwiftWatch* (Bird Studies Canada)

Appendix II: Glossary

Area of inference: Area to be represented by the data (e.g., province, ecozone, ecoregion).

Assessment: Scientists review and analyze data to determine the state of an ecosystem or species and identify changes that have occurred or are occurring.

Composition (species): The species that make up a community or ecosystem, or live in a defined area.

Ecosystem: A group of living organisms that interact and the non-living components of their environment (e.g., air, water, soil) that are linked together through nutrient cycles and energy flows.

Ecozone: Ecozones are broad ecosystem-based units used for assessment. They are classified using ecological, climate and topographic factors. Ontario is divided into four ecozones; they are the Hudson Plains, Boreal Shield, Mixedwood Plains, and Great Lakes. Ecozones do not respect political boundaries. Each of these ecozones also occupy parts of neighbouring provinces and states.

Habitat: Areas of land or water that organisms use to complete their life cycles (e.g., denning sites, foraging areas, migratory staging areas, nesting sites, overwintering areas), species they depend on (e.g., for food and shelter), and other environmental conditions (e.g., temperature, moisture, substrate) they need to survive and reproduce.

Indicator: An ecological indicator is a measure or collection of measures that describes the condition of an ecosystem or its critical components. Indicators must capture the complexity of ecosystems and be simple enough to be easily and routinely measured. Indicators are used to assess the condition of the environment, provide early warnings of change, and diagnose the cause of an environmental problem.

Inventory: An effort to identify and catalogue the flora and fauna in an ecosystem or defined area. An inventory describes the biological components of an ecosystem at a single point in time.

Landscape: A landscape is a heterogeneous area of land composed of a mosaic of interacting ecosystems.

Measurement variable: Measurement variables are the specific characteristics of an ecosystem, species or group of species that need to be monitored.

Monitoring: The systematic collection of data in a standardized manner at regular intervals over time (Spellerberg 2005). Long-term monitoring enhances knowledge of ecosystem processes, and helps to detect changes and trends in ecosystems (Vaughan *et al*. 2001).

Parameter of interest: Statistical measure that summarizes the target variable (e.g., mean, max/min).

Phenology: Phenology is the timing of seasonal activities such as flowering or breeding.

Population of interest: Species, group of species, or the entity that is being monitored.

Sampling intensity: Sample size for the desired precision of estimates.

Sampling unit: What it is we are actually measuring (e.g., tree height, fish fork length).

Sampling method: Process by which the entities of the sample have been measured (e.g., random, stratified).

Spatial resolution: Measurement scale as it relates to imagery (e.g., fine, medium, coarse).

Temporal resolution: Time between sampling events (e.g., data collected on a 5-year cycle).

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(0.2k P.R.,14 04 01)
ISBN 978-1-4606-3641-1 (print)
ISBN 978-1-4606-3642-8 (pdf)