An analysis of the vulnerabilities of Terrestrial Ecosystems/Vegetation Cover to climate change in the Lake Simcoe watershed

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INTRODUCTION

Over half of the Lake Simcoe watershed is in some form of natural vegetation cover, predominately comprised of forests and treed swamps (34%). The Lake Simcoe watershed is within the Mixedwood Plains Ecozone (Wickware and Rubec, 1989) and Lake Simcoe - Rideau Ecoregion (Ecoregion 6e). Most of the forest cover is found on less productive sand and till plain substrates and comprise 39% and 17%, respectively, of the remaining cover in this ecodistrict. Nearly 25% of the natural vegetation cover is comprised of wetlands, almost entirely composed of swamp forest complexes. Also 537.25 hectares of alvar and 30 hectares of tall grass prairie and savannah remain in the ecodistrict.

The amount of forest cover varies by quaternary watershed ranging from 14% to 79% (Figure 1). Watersheds with more productive agricultural soils (e.g., less than 17% forest cover in Maskinonge River, Barrie Creeks, Lovers Creek, and Hewitts Creek), have less remaining natural vegetation cover as well as more urban and developed lands. In contrast, quaternary watersheds with soils less suitable for agriculture and development have more remaining natural cover (e.g., over 40% forest cover in the Upper Talbot River, Hawkestone Creek, and Black River watersheds).

The natural forests and swamps in the watershed are predominantly dominated by deciduous tree species including sugar maple, red maple, yellow birch, red oak, basswood and white elm with some coniferous cover of white pine, red pine, and eastern hemlock. Other wide ranging species include eastern white cedar, largetooth aspen, beech, white oak and white ash (Hills 1959, Rowe 1972). These tree species are expected to respond to climate change stresses differently.

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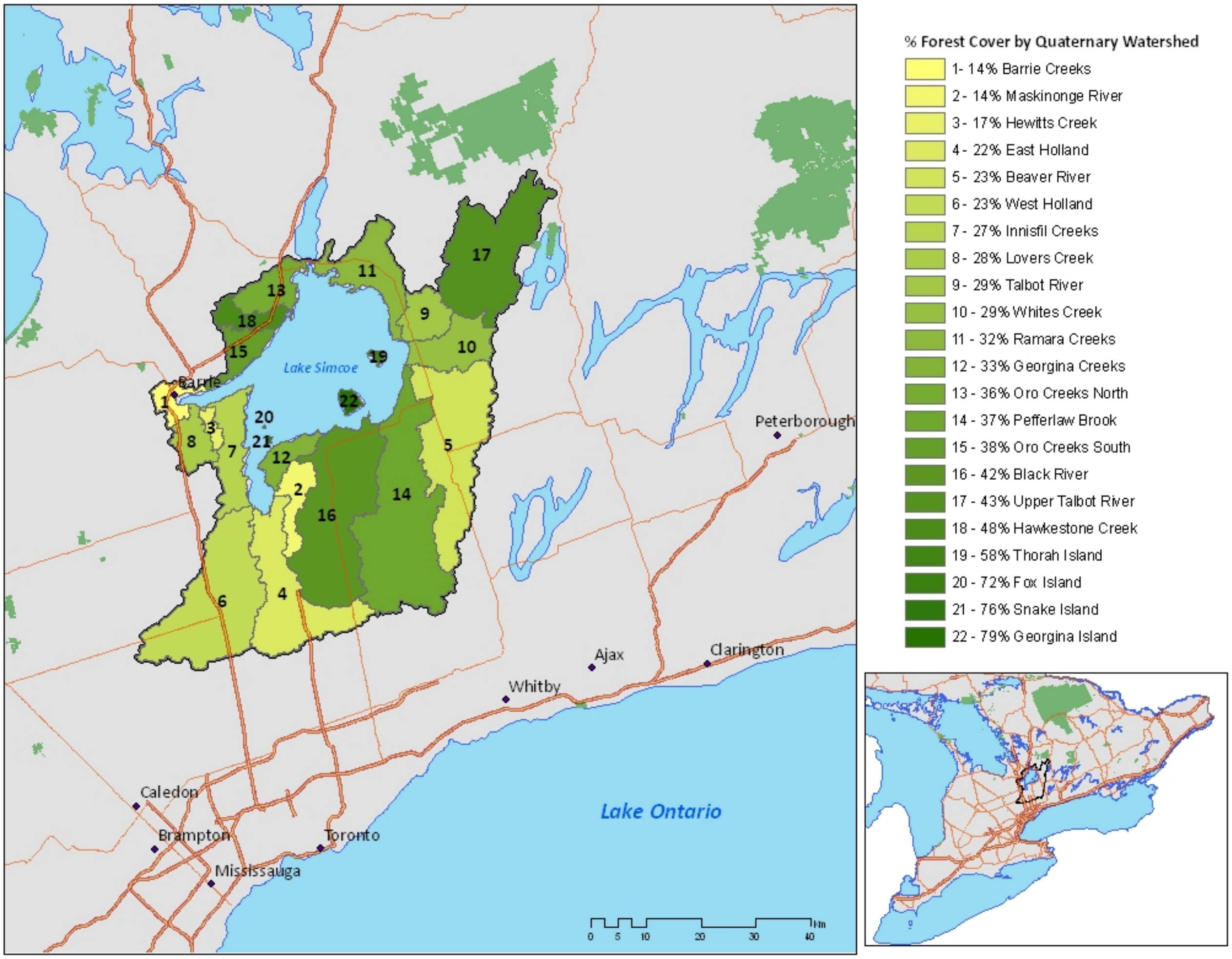


Figure 1: Forest cover by quaternary watershed in the Lake Simcoe basin.

Since most tree species are long-lived (e.g., sugar maple over 200 years, red oak up to 300 years; early successional species up to 100 years), species established under one climate condition could be exposed to a climate that is characteristic of the Carolinian zone in parts of the eastern United States within a period less than a half of their life span. Such rapid climate change is likely to have direct and indirect negative impacts on vegetation health, composition, structure and productivity, and be observed through changes in species range and distribution, abundance, health, phenology, seed production, germination and productivity. Varying individual species response to environmental and climate changes will result in rearranged species associations or vegetation types, and vegetation classes observed in today's forests and swamps may not be recognized in the future.

Forests, swamps and wetlands in this area are already subject to numerous anthropogenic pressures and the amount, composition and health of vegetation cover will continue to be negatively impacted by these activities. Further, these pressures are anticipated to interact in complex and unknown ways with climate induced stresses. Anthropogenic pressures include:

- Fragmentation of natural vegetation patches due to land development
- Indiscriminate forest clearing and harvesting without attention to silvicultural practices as demand for forest products, including wood biomass for energy, increases
- Increases in both number of and amount of cover of invasive species in natural areas
- Atmospheric and other pollutants.

Based on a literature review we compiled a list of potential climate change indicators for terrestrial vegetation that are relevant across different spatial and temporal scales (Table 1). Based on our knowledge of existing programs in southern Ontario we reviewed the current state of monitoring effort, and assessed the potential to monitor and report on each potential indicator (Table 2). Most of the indicators are not climate-change specific as they have been the focus, at various degrees and intensities, of vegetation monitoring and inventory for many years.

We considered modelling climate change impacts for several indicators of terrestrial vegetation, including species range and distribution, species abundance, invasive species distribution and abundance, tree biomass and growth, plant phenology, seed production and seed quality, and vegetation health, but as shown in Table 1 only the indicators “tree species distribution” and “tree species abundance” could be modeled based on available information.

Forests have been more adequately inventoried and mapped than any other vegetation due to their commercial timber value. Since forests are the predominant natural vegetation cover in southern Ontario and the Lake Simcoe watershed, we proposed to predict tree species distribution and abundance models for different climate change scenarios. Such models would provide not only an indication of impacts to forests but also indirect affects on wildlife habitat and ecological goods and services. For this report we considered models of tree species distribution and abundance, and identified changes in forest composition. This report contains the findings related to the abundance and distribution of Ontario tree species under the Canadian Climate Model Version 2 for the three standard future time periods: 2011-2040, 2041-2070 and 2071-2100.

METHODOLOGY

The tree species models and vegetation and environmental data sets used to develop and validate existing and future tree species distribution and abundance were previously developed by Malcolm, Puric-Mladenovic, and Shi in an earlier study (Malcolm et al. 2003, 2005). An ecological niche modeling approach was used to develop individual tree species models i.e., predictive maps of species distribution were generated for the Lake Simcoe basin and Ontario based on both individual tree species known distribution and environmental data such as temperature, altitude, substrate, etc. These models in combination with future climate models were used to project the potential future distribution of individual tree species for the Lake Simcoe quaternary watershed in Ontario. The maps of future distribution show areas where a species is expected to survive assuming that migration can occur from current locations across potentially unsuitable environments (Malcolm et al. 2003, 2005).

Tree species models were based on extensive datasets of tree presence/absence and underlying environmental information (climate, soils, topography, and land-use) compiled for a wide ranging area that included both the province of Ontario, Canada, and the eastern United States (east of 100º W longitude). The eastern US was included because it both comprises the southern range of many Ontario tree species and supports species that could find suitable habitat conditions in the Lake Simcoe Watershed under future climate scenarios.

Models and data sets used to validate the tree species models were developed by Malcolm, Puric-Mladenovic, and Shi (Malcolm et al. 2003, 2005). Tree abundance and distribution in Ontario was compiled at a spatial resolution of 300 arc-seconds (approximately 7-8 km) which corresponds to the resolution of Version 2 of the Canadian Climate Model and several other key environmental data sets. This scale was also chosen because it approximated the 20-km scale used by Prasad and Iverson (1998, 2002), hence enabling incorporation of their data on eastern US tree distributions and associated environmental variables.

Presence and absence of 66 and 64 tree species from Ontario and the eastern US, respectively, were modeled. In addition, abundance of 17 Ontario tree species was modeled. Using the projected species abundance information, future vegetation assemblages (aka vegetation types) were derived using statistical clustering.

The analysis and findings are presented at the resolution of the climate grid (300 arc-seconds) as well as by the 18 quaternary watershed polygons within the Lake Simcoe basin. Vulnerability was assessed based on the species distribution and abundance for Canadian Climate Model Version 2 climate scenarios for three time periods (2011-2040, 2041-2070 and 2071-2100) by quaternary watershed.

Table 1: Review of potential indicators for measuring climate change impacts to terrestrial vegetation and approaches for deriving indicator, including references.

Indicator	Climate Change Impact to Indicator	Approach to deriving indicator, including references
Species range and distribution	The most extreme climate scenarios predict changes in range size up to approximately 120,000 km^2 which would result in significant shifts in tree species distribution. Some southern species could extend their range and find suitable habitat and environmental conditions in the distant north, while it is expected that ranges of northern species will decrease. Species with narrow ranges or at the northern most range of their distribution will likely experience shifts at sub-regional or watershed scales while wider ranging species will experience more noticeable shifts at a regional scale.	*Regional and local range* and distribution under existing and future climate scenarios. **References:** Iverson and Prasad, 1998, 2002; Malcolm et al 2003, 2005; McKenney, et al. 2010; Iverson and Prasad, 1998, 2002.
Species abundance	Species response to climate change is individualistic. While species may extend or decrease their range, associated decreases or increases in species abundance are also likely to occur. A combination of distributional shifts and species abundance changes are likely to result in new vegetation types not observed in today's landscape. These in turn may have impacts on associated ground vegetation, wildlife, and ecological goods and services, as well as associated implications for management and conservation activities.	Quantitatively measured ***local abundance*** serves as both a local and regional indicator. **Regional indicators:** derived from local abundance measured and extrapolated across the landscape. **Composite indicators:** local / ground measured abundances combined and integrated with satellite images provide a powerful tool for forecasting changes across landscapes and fast adaptation to the impacts of climate change. **References:** Iverson and Prasad, 1998, 2002; Malcolm et al 2003, 2005; McKenney, et al. 2010; Iverson and Prasad, 1998, 2002.
Invasive species distribution and abundance	Climate change is likely to have both direct and indirect impacts on invasive species. It could contribute to an increase and faster movement of invasive species and / or contribute to degradations of native vegetation that favour invasive species. Some invasive plant species are likely to respond positively to climate change, and as a result extend their range, and increase in abundance, which all could have an impact or native vegetation.	Invasive species distribution and range. Invasive species abundance. **References:** Burgiel and Muir. 2010, Ibanez, et al. 2009.
Tree biomass and growth	Identifying rates of change in biomass and plant growth across species and landscapes can identify whether some species positively respond to prolonged growing seasons. Species that are likely to respond favourably are wide ranging and early successional, fast growing species.	Tree growth rates and changes over a period of time Changes in tree species growth curves over time periods. **References:** Jacob et al. 2010; McMahon et al., 2010; Myneni et al. 1997.

Indicator	Climate Change Impact to Indicator	Approach to deriving indicator, including references
Seed production	The ability of plants to produce seed of good quantity and quality that can be dispersed and enable plant establishment is critical plant adaptation mechanism to respond to climate change. Climate change is likely to affect seed production and in the case of extreme events (e.g., early spring frosts, extensive droughts) may result in growth declines, damage to flowers and leaf buds, and/or seed mortality. For example, earlier flowering and leaf out in combination with late spring frosts are likely to negatively impact seed production. This will exacerbate normal seed crop periodicity, and could decrease already narrow windows for seed collection for some species.	**Indicators**: *Seed abundance* and frequency by crop year in relation to climate and spatial location. *Seed quality* –germination success by crop year in relation to climate and spatial location. **References:** Boden et al. 2010; Colombo et al. 2008; Harsch et al. 2009; Vitt et al. 2010.
Species phenology	The timing of phenological events is sensitive to both short- and long-term variability in climate, and therefore is a robust indicator of the effects of climate change. Early spring leaf-out and flowering, and leaf senescence are likely the best indicators of climate trends at the local scale, but are also applicable at the regional scale. Phenology of urban vegetation should be observed separately due to heat-island effects.	**Local on-the-ground indicators:** Measure and observe phenological events for different species. **Regional indicators:** Derived from local trends in species' phenology. Satellite images can also be used to track phenological changes. **Composite indicators:** Integrate phenological observations and climate models to create a powerful tool for forecasting and adapting to the impacts of climate change. **References:** Altermatt, 2010; Chuine, et al. 2000; Fujisawa and Kobayashi 2010; Gazal et al. 2008; Gordo and Jose Sanz, 2010; Menzel et al. 2006; Morin et al. 2009; Primack and Higuchi, 2006; Richardson et al. 2006; Schwartz et al. 2006; White et al. 2009; Zhang et al. 2007.
Vegetation health	Changes in climatic conditions and pattern, can directly, indirectly or in combination with other factors impact vegetation health. Evaluating and assessing health of vegetation and in particular forest ecosystem and tree species have been used to detect and evaluate impacts of environmental pollution and various abiotic and biotic stressor for decades. Adding climate change impacts to these magnifies the existing problems.	**Local on-the-ground indicators:** Measure and observe health of individual trees and vegetation. **Regional indicators:** Extrapolate local vegetation health measurements across landscapes. Satellite images can also be used to monitor, detect changes and monitor vegetation health across larger areas. **Composite indicators:** The integration of on-ground observation, satellite images creates a powerful tool for monitoring health across landscapes and prioritizing management and adaptation activities. **References:** Hellmann et al. 2010; Moore and Allard, 200.

Table 2: Proposed indicators for monitoring climate change impacts on terrestrial vegetation, rationale for indicator, current state of monitoring effort (including required data), and assessment of whether it is currently possible to monitor and report on the indicator.

Indicator	Rationale and Current State of Data	Current Monitoring and Reporting Capacity
Species range and distribution	**Rationale:** Regional vegetation and species range and distribution are primarily defined and driven by climate. **Required data**: Historical and current vegetation information and inventories that are spatial or can be spatially referenced. Required minimum is that this information can be translated into species presence / absence with relatively accurate geographic location. **Available data:** Information and data sources that can be used include forest inventories, ecological land classification, species at risk records, plant databases, herbarium records, species range maps, etc.	This is probably the easiest indicator to model and assess simply by using range maps and existing inventories. However, to predict more relevant fine-scale species distribution and shifts, more detailed inventory and sampling data is required. If regular inventories are conducted, it would be possible to track and measure how quickly species ranges are responding to climate change shifts. A set of indicator species, across different vegetation forms, could be selected to monitor the on-the-ground response.
Species abundance	**Rationale:** Species abundance across landscape varies due to environmental characteristics (environmental gradients), species competition and disturbances including human induced activities. Within the optimal climate environment, species abundances are typically higher, while at the tail-end of range distributions, species abundances are usually lower. **Required data**: Quantitative vegetation inventory information based on standard abundance measures (e.g., counts, percent cover). **Available data:** Forest Resources Inventory (FRI), MNR forest productivity plots, MOE forest health plots, historical Maycock plots in southern Ontario, National Forest Inventory (NFI) plots, Vegetation Survey Plots, other research plots.	Current monitoring programs were designed at different scales and for different purposes (e.g., Federal NFI plots) and may not provide sufficient data at finer scales. The provincial (MNR) Forest Productivity Plot network does not have sufficient plots in many southern Ontario forest vegetation types to support modelling. Many existing plot-based inventory programs are infrequently monitored due to lack of funding. A review of existing plot-based programs is required to assess their applicability for strategic, systematic climate change monitoring and to identify gaps in geographic and vegetation type representation. No monitoring networks have been established for non-forest vegetation types.
Invasive species distribution and abundance	A number of invasive plants, insects and pathogens have already permanently changed southern Ontario's forests (e.g., Dutch Elm Disease and Chestnut Blight). **Available data:** Vegetation inventories and invasive species information from the Invasive Tracking System (Ontario Invasive Plant Council), the Canadian Food Inspection Agency (CFIA), Canadian Forest Service (CFS), Ministry of Agriculture, urban forest inventories, etc.	Invasive species inventory and monitoring can be incorporated in current vegetation inventory and monitoring programs. If an invasive species becomes a treat, separate and more intensive inventories and monitoring may be required. Currently, no strategic and systematic inventory of invasive species is conducted.

Indicator	Rationale and Current State of Data	Current Monitoring and Reporting Capacity
Tree biomass and growth	Recent research studies have related changes in tree growth and increased biomass production across many forest types to climate change. **Required data**: Quantitative individual tree measurements (e.g., height, diameter at breast height, volume, biomass). **Available data**: MNR forest productivity plots (Growth and Yield Plots).	To detect trends and confidently relate these to climate change, more plots are needed across landscapes, different vegetation classes and environments. In addition, their measurements at regular time intervals are necessary.
Plant phenology	Plant phenology refers to the timing of seasonal plant activities (e.g., budbreak, flowering, or autumn leaf senescence) which are predominantly driven by climate. Plant phenology has been monitored for decades in other parts of the world and recently has been revisited as an indicator of climate change. **Available data**: Plant phenology information from agricultural records (e.g. flowering of fruit trees); start of sugar maple tapping; records from botanical gardens, environmental records on pollen-release; satellite images (e.g., NDVI from MODIS, LANDSAT).	No systematic and strategic monitoring of vegetation phenology occurs in Ontario. No monitoring networks have been established for non-forest vegetation types.
Seed production and seed quality	The ability of plants to produce seed of good quantity and quality that can be dispersed and enable plant establishment is a critical and probably the most important to adaptation strategy to climate change. **Available data**: Seed crop forecasting information from the Ontario Tree Seed Plant and the Forest Gene Conservation Association (FGCA).	No systematic and strategic monitoring of seed quality and abundance occurs in Ontario.
Vegetation health	Evaluating and assessing health of forest ecosystem and tree species has been used as an indicator of environmental pollution, stress, insect and pathogen impacts for many years. Climate change in combination with other biotic and abiotic stressors is likely to impact health of terrestrial vegetation. **Available data**: Tree health information from MNR/CFS forest health monitoring efforts, MNR forest productivity and MOE forest health plots.	A review of existing plot-based programs is required to assess their applicability for strategic, systematic climate change monitoring and to identify gaps in geographic and vegetation type representation. No similar monitoring networks have been established for non-forest vegetation types.

RESULTS AND DISCUSSION

The species models indicate that changes in tree abundance are likely to be influenced by future climate change. Shifts in tree species distribution due to climate change are likely to occur at a fast pace and across wide-ranging landscapes. Figure 2 shows the vulnerability of 17 tree species to climate change. Vulnerability is expressed as the coefficient of variation (y axis) of species abundance for four climate periods from 1960 to 2100. Abundance for each modeled tree species is likely to decline, however the magnitude of the decline differs by species (x axis). While some species like white cedar (THUJOCCI), black ash (FRAXNIG) and red oak (QUERRUBR) will be more resilient and able to adapt to the new environment, others like yellow birch (BETUALLE) and hemlock (TSUGCANA) will likely be less abundant within the watershed.

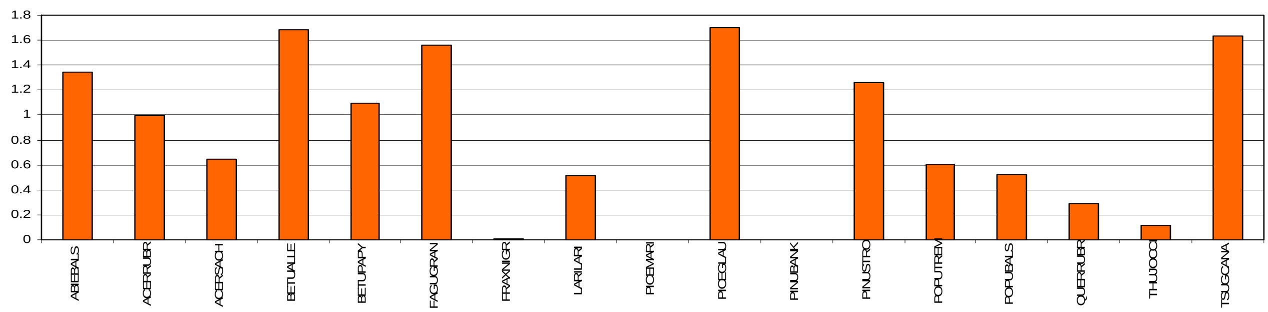


Figure 2: Vulnerability of species, expressed as the coefficient of variation of species abundance from 1960 – 2100, to climate change.

When the change in species vulnerability was compared over two future time periods (2011-2070 and 2011 to 2100), most species' models showed that their abundance will already decline substantially by 2070. Only the sugar maple (ACERSACH) model (Figure 3) indicates that abundance of this species is likely to stay stable until after 2071.

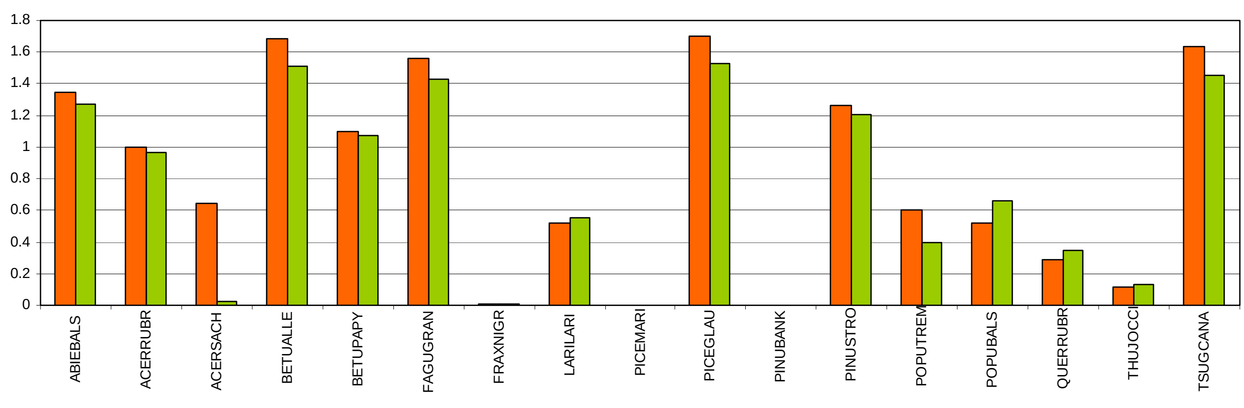


Figure 3: Comparison of species vulnerability, expressed as the coefficient of variation in species abundance over two future time periods 2011-2070 (orange) and 2011-2100 (green).

More details on predicted species abundance declines can be inferred by plotting predicted change in average abundance for the current and three future time periods (i.e., 1961-1990, 2011-2040, 2041-2070, and 2071-2100) to compare species' vulnerabilities to climate change. Figure 4 shows the predicted change in average abundance for three species, red maple (ACERRUBR), white pine (PINUSTRO), and sugar maple (ACERSACH), all of which are expected to decline in abundance compared to current conditions (1961-1990).

Figure 4 also shows that the changes in average abundance are unique to each species, and as a result will contribute to the assembly of new vegetation types as some species will likely reproduce and/or survive at different rates. Without assisted migration, it is uncertain that southern tree species (not currently known in the Lake Simcoe watershed) will be able to move into these vacated habitats quickly enough given the fragmented forest landscape conditions south, west and east of the watershed.

Figure 4 shows that the local distribution of sugar maple (ACERSACH) for the Lake Simcoe watershed, based on the modeling, remains stable until 2070. After this period, abundance is predicted to decline precipitously. This indicates that if this species is monitored at the watershed scale, changes in its distribution are likely to be observed too late. Hence the importance of regional monitoring, beyond the scale of a single watershed, in order to anticipate and adapt to upcoming changes.

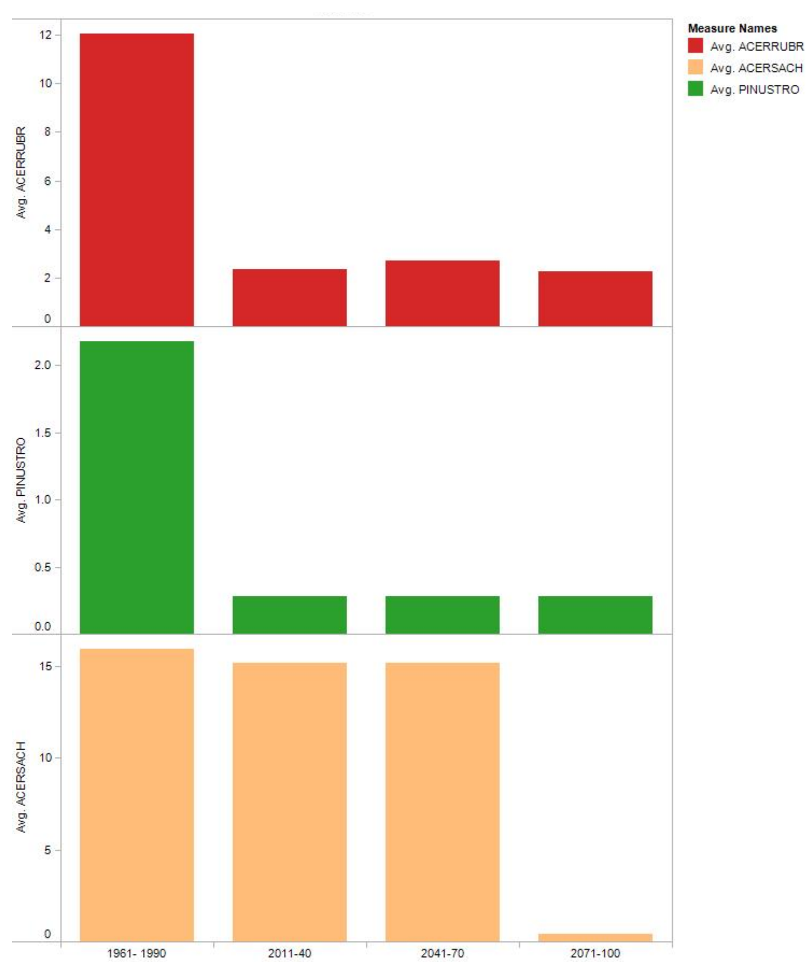


Figure 4: Predicted change in average abundance for red maple (ACERRUBR), white pine (PINUSTRO) and sugar maple (ACERSACH) in the Lake Simcoe watershed for four time periods (1961-1990, 2011-2040, 2041-2070, and 2071-2100).

More information on predicted species declines can be inferred by plotting predicted change in average abundance for the current and three future time periods (1961-1990, 2011-2040, 2041-2070) across the Lake Simcoe quaternary watersheds. Figure 5 shows that predicted change in average abundance for red maple (ACERRUBR) varies across the watershed. While abundance of this species under future climate conditions is less than for current conditions, its distribution and abundance within the watershed is likely to shift from west to east due to a combination of climatic and other environmental drivers (e.g., soil texture and moisture). If the species models only considered climatic inputs, species shifts would follow a latitudinal trend similar to predominant climatic (temperature) patterns. However, since the species models incorporated soil texture, soil moisture, topography and landscape characteristics, the autecology of each species is also considered in modelling climate change response.

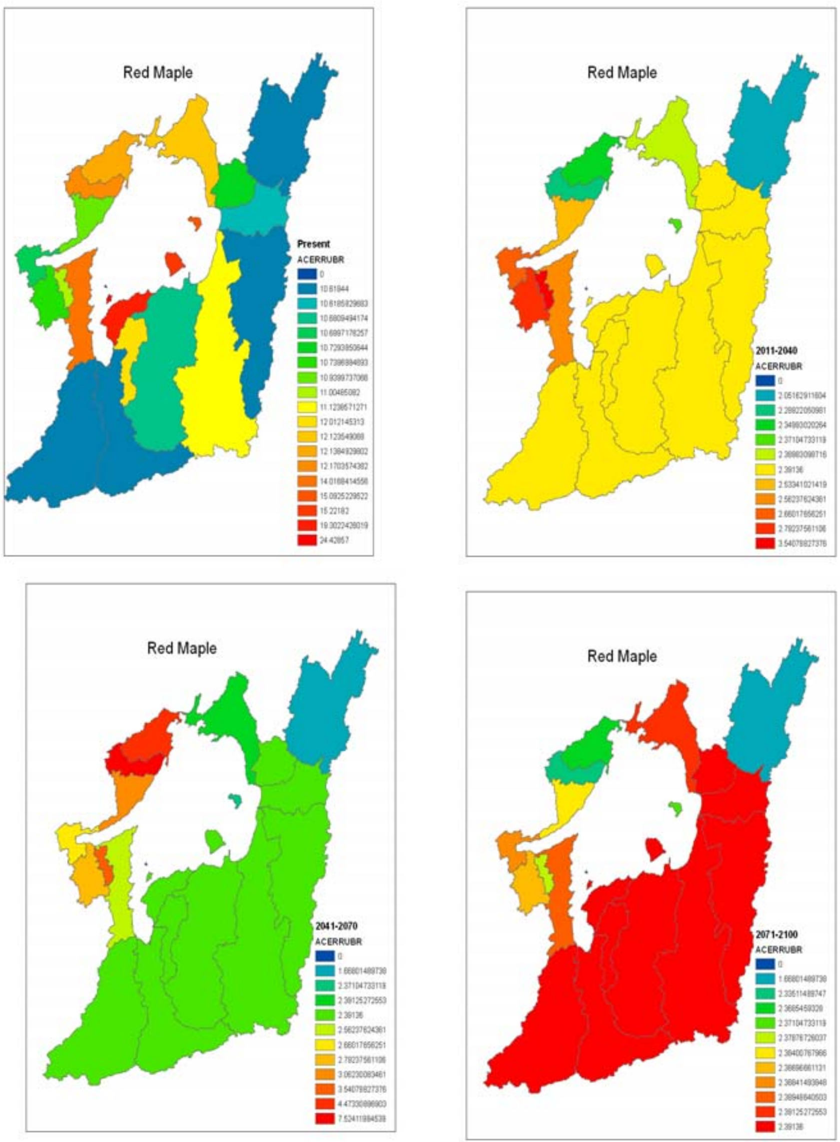


Figure 5: Average abundance of red maple (*Acer rubrum)* in Lake Simcoe quaternary watersheds for four different time periods, 1961-1990 (upper left), 2011-2040 (upper right), 2041-2070 (lower left), and 2071-2100 (lower right).

Change in average abundance for white pine (PINUSTRO) across the Lake Simcoe watershed is predicted to precipitously decline as shown by the variation in its abundance from 2.3 for 1960-91 to 0.25 for the 2071-2100 future time period. Significant changes in abundance and species distribution across most quaternary watersheds in the Lake Simcoe area is likely to occur. The modeling results show that after 2040, the north-western quaternary watersheds are expected to provide more stable habitat conditions than any other Lake Simcoe watersheds (Figure 6). Species abundance in these quaternary watersheds is likely to remain stable, as soil, topography, and existing forest cover (36 – 48 %) conditions likely will moderate climate impacts on white pine distribution in these areas. Thus, some quaternary watersheds in the Lake Simcoe basin could provide refuge areas for some species.

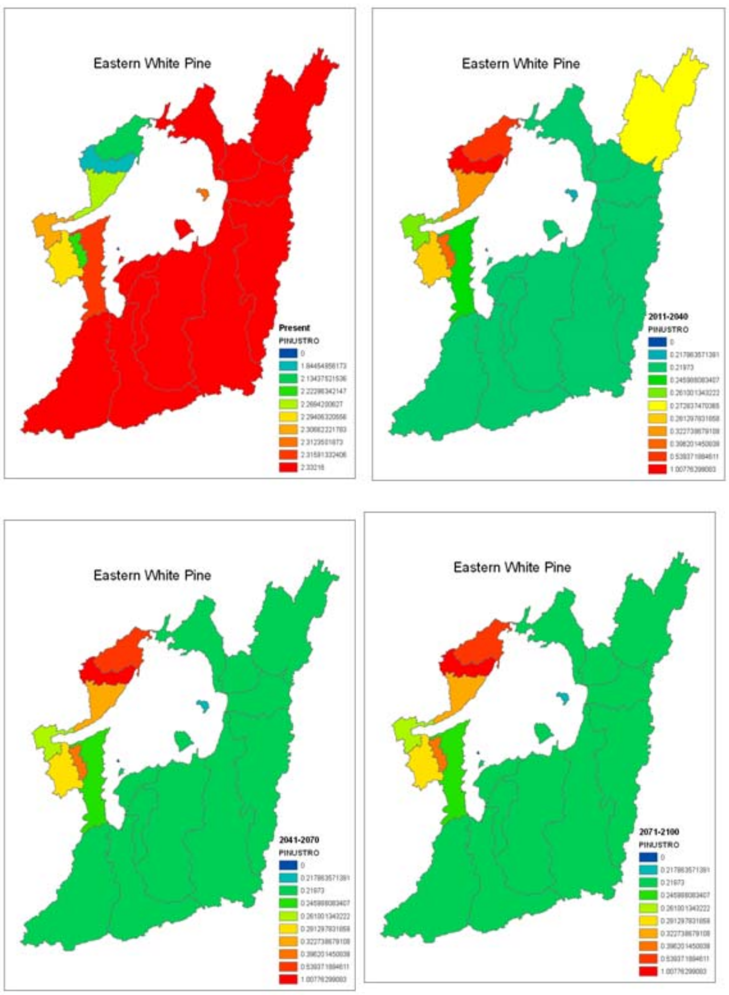


Figure 6: Average abundance of Eastern white pine (*Pinus strobus*) in Lake Simcoe quaternary watersheds for four different time periods 1961-1990 (upper left), 2011-2040 (upper right), 2041-2070 (lower left), and 2071-2100 (lower right).

To ascertain if these north-western quaternary watersheds are refugia for white pine across southern Ontario, or just within the Lake Simcoe basin, distribution for this species was also modelled across Ontario for different future climate periods. Figure 7 identifies these quaternary watersheds, or portions thereof, to be only one of two areas south of the Canadian Shield expected to provide suitable habitat conditions for white pine. An adaptation strategy for the Lake Simcoe basin might identify the importance of these watersheds as refugia for white pine (and potentially other species, including associated wildlife species) based on this modelling. It will be critical to regularly monitor tree species changes at both the regional (southern Ontario) and Lake Simcoe basin scales in order to anticipate and adapt to future climate change impacts.

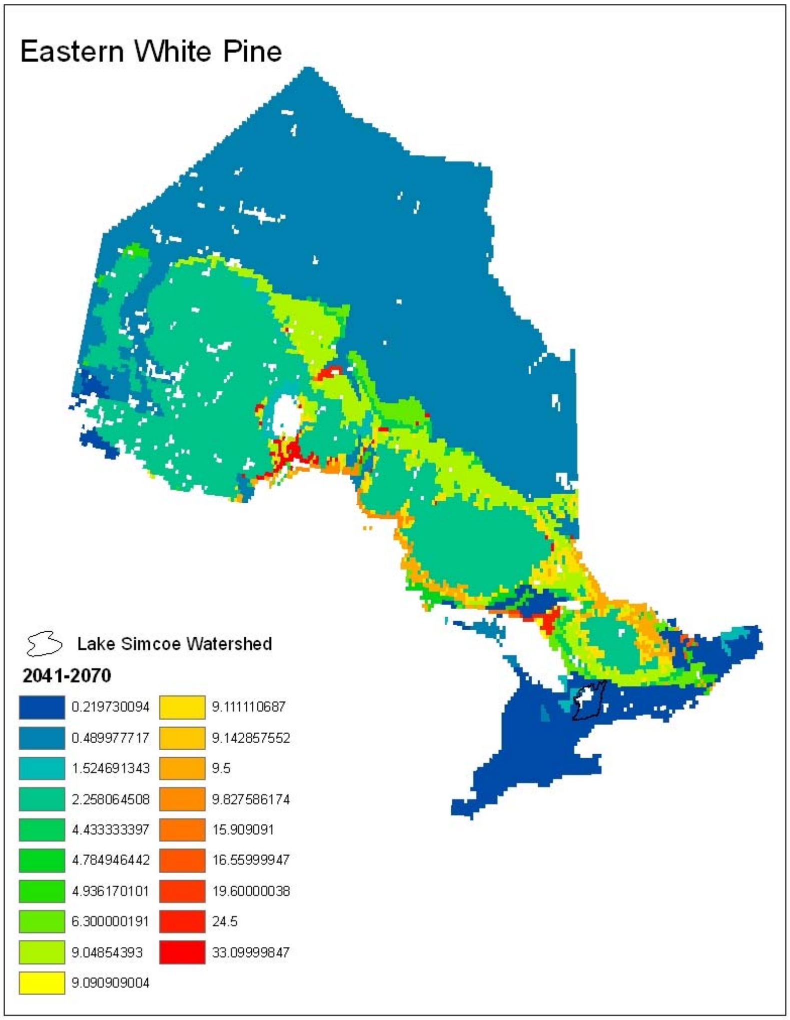


Figure 7: Average abundance of Eastern white pine (*Pinus strobus*) across Ontario for the 2041-2070 future time period.

Change in average abundance for sugar maple (ACERSACH) is predicted to sharply decline across the Lake Simcoe quaternary watersheds after 2071 (Figure 8). Sugar maple abundance for the periods 2011-40 and 2040-70 remains stable in the Lake Simcoe basin. However, after 2070 models indicate that this species abundance will sharply decline not just across the entire Lake Simcoe watershed, but also across most of southern Ontario and most of the mixed-forest region (Figure 9). This result of the modelling again underscores the importance of regular monitoring efforts at a scale beyond the Lake Simcoe basin in order to anticipate potential future changes at the watershed scale. For example, while the decline of sugar maple abundance may not be evident until 2070 in the Lake Simcoe basin, at the Ontario scale declines in abundance of this species are already evident in the modelling results for the first time period (2011-2040). As a result, indicators of climate change and monitoring efforts need to be applicable, relevant and interchangeable across provincial, regional and watershed scales.

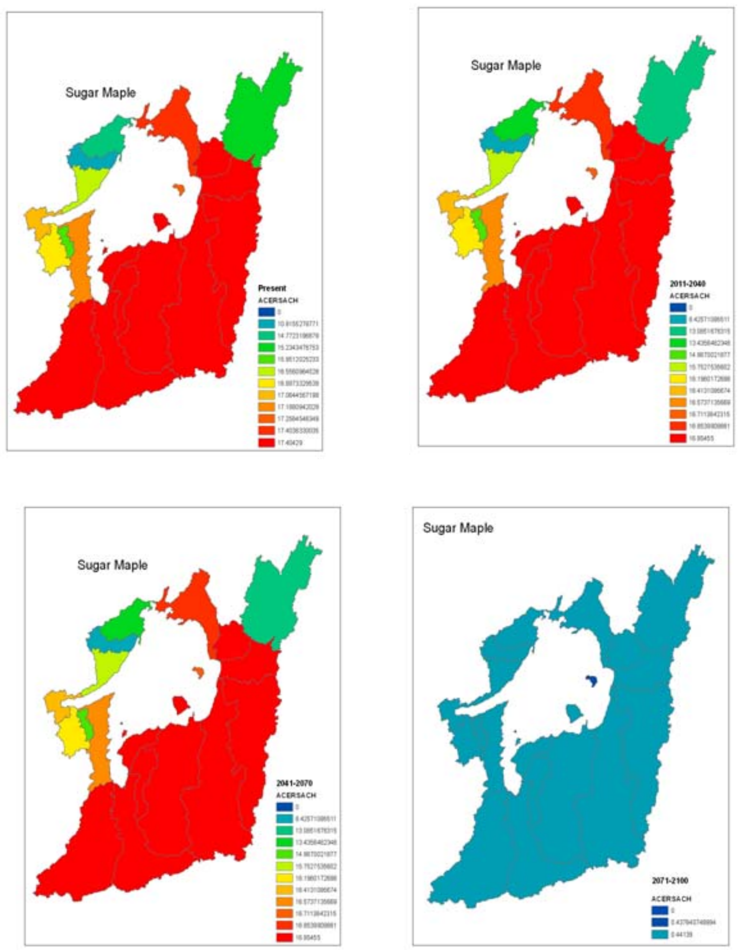
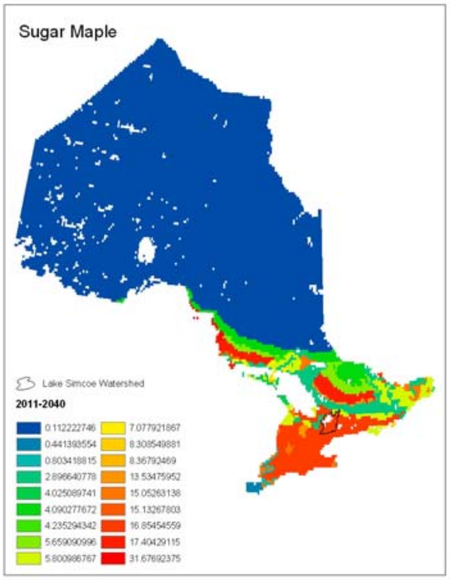
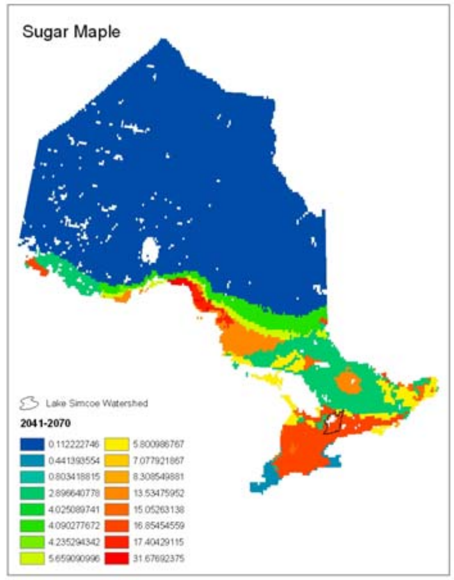


Figure 8: Average abundance of sugar maple (*Acer saccharum*) in Lake Simcoe quaternary watersheds for four different time periods 1961-1990 (upper left), 2011-2040 (upper right), 2041-2070 (lower left), and 2071-2100 (lower right). Abundance is not predicted to precipitously decline until the last future period (2071-2100).





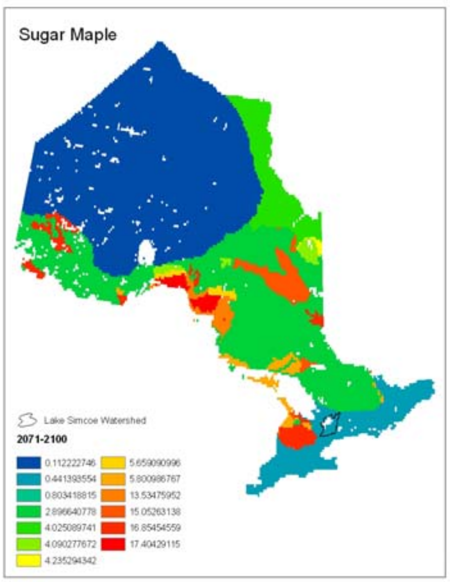


Figure 9: Average abundance of sugar maple (*Acer saccharum*) for Ontario for three climate periods, 2011-2040 (upper left), 2041-2070 (upper right), and 2071-2100 (lower left). Sugar maple abundance does not precipitously decline until after 2071.

Predictions for distribution and abundance of other tree species for the four climate periods are provided in the Appendices. Species distribution maps in Appendix 1 indicate that some species with current ranges in southwestern Ontario (e.g., shellbark hickory or *Carya laciniosa*), or the midwestern US (e.g., Ohio Buckeye[5] or *Aesculus glabra)* and even the southwestern US (e.g., black hickory or *Carya texana*) may find suitable conditions in the Lake Simcoe basin by 2071-2100. Some southwestern Ontario species such as tulip tree (*Liriodendron tulipifera* , cucumber tree (*Magnolia acuminate*) and Shumard oak (*Quercus shumardii*) are not expected to find suitable habitat conditions in

[5] A natural population of large trees of this species occurs on Walpole Island at the north end of Lake St. Clari (Farrar 1995).

the Lake Simcoe basin while the models indicate that others like red mulberry *(Morus rubra*), black gum (*Nyssa sylvatica*) and wwamp white oak *(Quercus bicolor*) may (Appendix 2).

Although the net effect of the northward shifts in climate at the provincial scale was a consistent and large increase in tree species richness in the province, especially in the south where average richness more than doubled from approximately 11-12 species to more than 25 (Malcolm et al. 2003, 2005), native Ontario tree species diversity (based on current distribution) in the Lake Simcoe basin is expected to decline after 2011 from a high of 33 species (in the East Holland watershed) to highs of only 23 species in five quaternary watersheds (Figure 10).

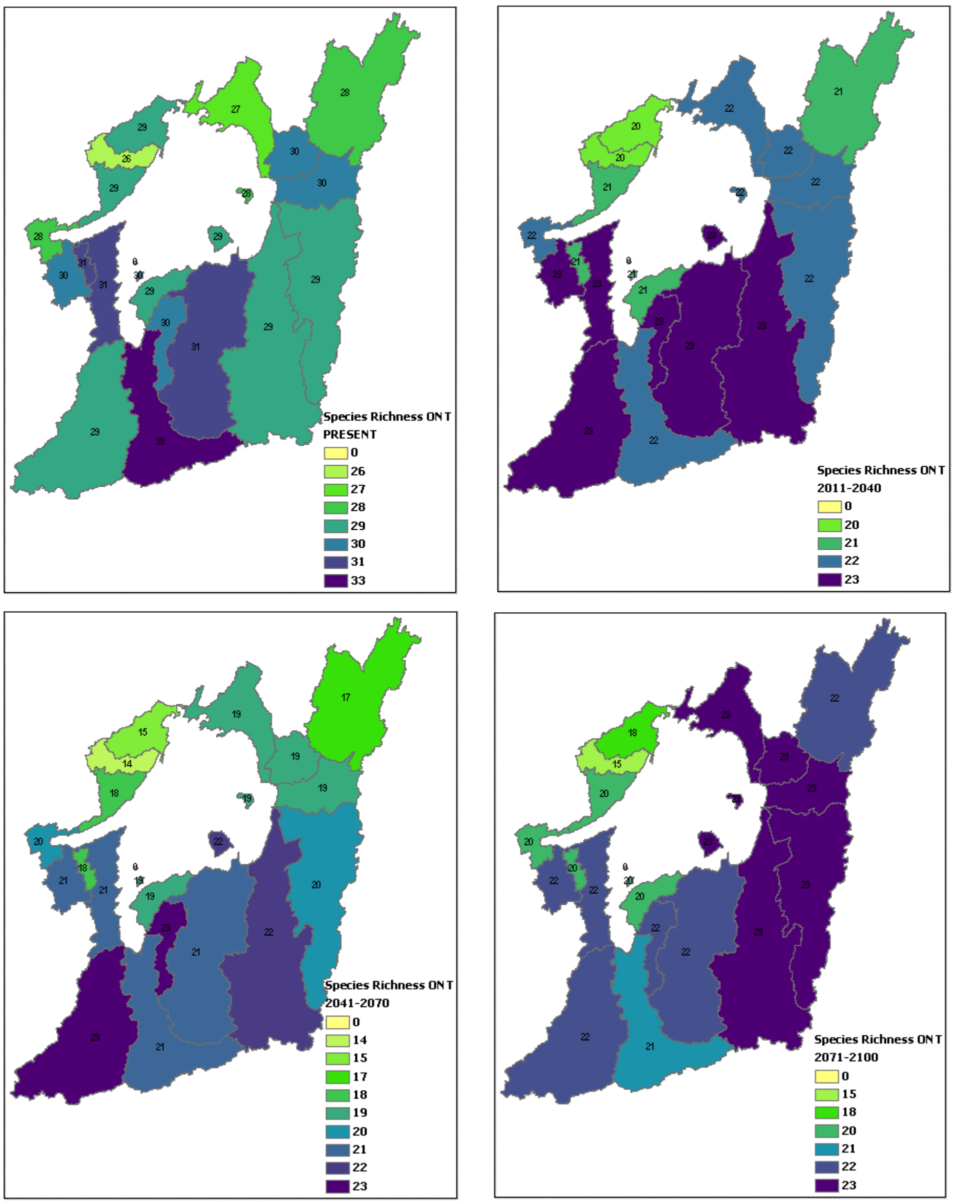
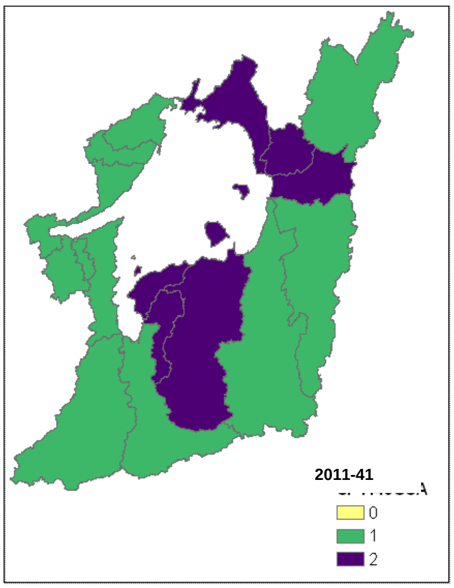
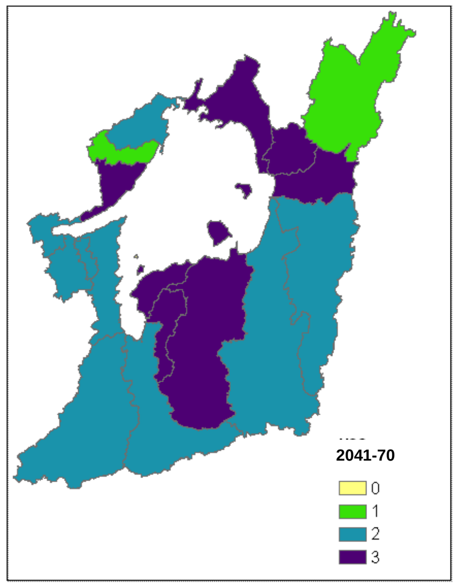


Figure 10: Species richness expressed as numbers of native Ontario tree species that could be present in the Lake Simcoe watershed for four different time periods 1961-1990 (upper left), 2011-2040 (upper right), 2041-2070 (lower left), and 2071-2100 (lower right).

The models indicate that quaternary watersheds in the Lake Simcoe basin will lose more Ontario native tree species diversity than will be gained through northward migration of native tree species from the US (Figure 11). However, the extent to which the tree species models reflect future species distributions will depend on a number of factors, including the nature, complexity, and accuracy of the models and the quality of the environmental data layers used. Further, the influence of non-niche factors such as barriers to dispersal, geologic history, or competing species, that may prevent the occupation of any potential niches identified by the model, cannot yet be accommodated by these models.





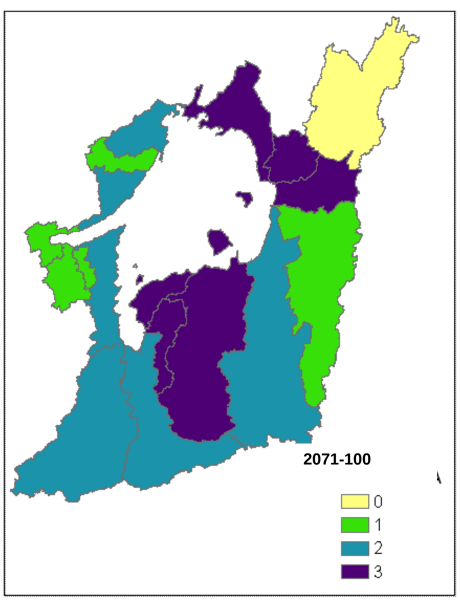


Figure 11: Number of US species that could find potentially suitable climatic and environmental conditions in Lake Simcoe quaternary watersheds for three climate periods, 2011-2040 (upper left), 2041-2070 (upper right), and 2071-2100 (lower left).

RECOMMENDATIONS

Climate change is a regional and continental phenomenon, and thus there is a need to standardize inventories and monitoring across a range of scales from local to regional scale to provincial. The development of a strategic, coordinated and integrated climate change monitoring program for terrestrial vegetation would benefit from efforts to harmonize available historical and current vegetation inventory information to provide a solid baseline from which to both observe changes in species ranges and forecast future vulnerabilities across different scales.

A next step might develop an analysis of monitoring options for the potential climate change indicators identified in Tables 1 and 2, incorporating current monitoring activities and future estimated costs. While commonplace in other parts of the world, long-term observations of the phenology of native tree species and plants are rarely documented in Ontario except by a few citizen scientists. Simply monitoring phenological events by species is probably the quickest way to detect impacts of climate change on the ground. An analysis of options should also identify opportunities and costs for inventories of other natural and semi-natural vegetation communities, including grasslands, shrub-thickets, and early successional forests in order to elucidate succession pathways. In addition, newer technologies such as use of remote sensing data, along with inventory, monitoring and on-ground observational information could support regional trend analysis and mapping.

Once a suite of climate change indicators are identified and a terrestrial vegetation monitoring option is chosen, monitoring should be integrated with current management and conservation activities as much as possible. Future vegetation inventory efforts should be based on standard protocols that collect quantitative data such as species composition and abundance (e.g., percent cover), and repeatable tree growth measurements (e.g., height, diameter, etc.) from fixed plots that are strategically located across Ontario. As this study has demonstrated, tree species will respond uniquely and at different rates to climate change, resulting in new vegetation types that will not resemble those seen in today's forests nor described by current vegetation classification systems which will quickly become outdated. Given the changes in tree species distribution predicted by the models in this study, regular collection and analysis of quantitative vegetation data will be critical and can support a variety of applications and business needs at different scales (Iverson and Prasad, 1998, 2002; Nabuurs et al. 2001; Rudis, 2003).

The many conservation organizations that manage resources in the Lake Simcoe basin and across the southern region of Ontario likely each have a role in vegetation monitoring, but currently these are not clearly articulated or well-established. Current vegetation inventory efforts need to be strategic, integrated and coordinated across organizations and programs to ensure that the data collected has the statistical rigour required to detect real changes to terrestrial vegetation. Only then can this information be used to assess species vulnerabilities across different scales, and develop adaptation strategies for individual species (e.g., assisted migration, seed preservation, etc.). Even if existing vegetation inventory activities could be redirected to be more strategic, integrated and coordinated, it is likely that current levels of investment in data collection, data management, analysis and reporting will need to be increased in order to adapt to the magnitude of potential climate change impacts to terrestrial vegetation predicted by this modelling work. The numerous ecological goods and services provided by terrestrial vegetation cover, and in some cases highly valuable economic activities dependent on a single tree species e.g., maple syrup production, should be a convincing argument for the need to enhance current vegetation inventory efforts.

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