A MORE RESILIENT WOODLOT

HOW TO MAKE YOUR WOODLOT MORE RESILIENT TO BIOTIC (INSECTS AND PESTS) AND ABIOTIC (CLIMATE CHANGE) THREATS

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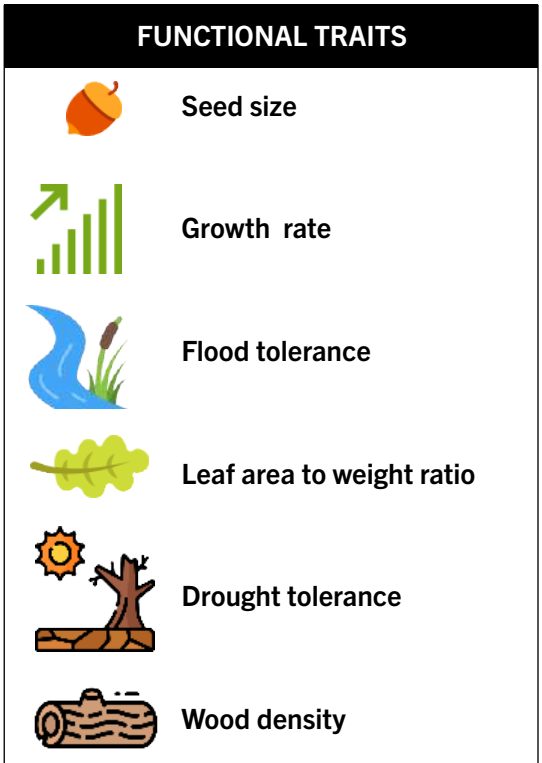
In the current context of accelerating global changes (e.g., rapid climate change, fragmentation of forest landscapes, pollution, introduction of invasive species), all living things will need to adapt to these new conditions, and trees and forests are no exception. In addition to a changing climate — characterized by more extreme weather events (strong winds, storms, prolonged droughts, etc.) — and the spread of new exotic insects and diseases across the world, there is also growing uncertainty about the future socio-economic value of our forests. We are increasingly less able to predict the future biotic and abiotic conditions our trees will face, or which tree species or ecosystem services will be most valued in the future. Although this growing uncertainty makes long-term forest planning extremely difficult, the way we manage our woodlots must change. We need to move from management based on certainty and the production of well-defined products and services (syrup, quality hardwoods, construction timber, etc.) to management based on uncertainty and increased resilience to face global changes.

HOW TO MANAGE UNCERTAINTY AND RESILIENCE: THE FUNCTIONAL DIVERSITY APPROACH

It is now increasingly recognized that a great diversity of tree species increases the resilience of forests to disturbances. I use the term resilience here in a very general way to refer to the capacity of a forest, following one or more disturbances or stress, 1) to either resist, or to recover quickly while maintaining its structure and composition or, 2) to change its structure and composition to adapt and maintain its main functions. Although we generally use the number of species to assess the diversity of a forest, this value does not give us any information on the equitability of the species present (a measure of how even the proportion of species is in a stand) or on the diversity of ecological or functional characteristics of those species or functional diversity. A woodlot with 10 tree species in equal proportion (equitability index = 1.0) is clearly more diverse than another with the same 10 tree species where two species represent 95% of the basal area (equitability index = 0.1). Likewise, it is easy to understand that a woodlot with 10 species of trees in equal proportion, including four species of maple, three species of pine and three species of poplar is less diverse functionally speaking (functional diversity of 2.1) (see Figure 1) than another woodlot with 10 species of trees in equal proportion, including two species of maple, one of fir, one of spruce, two of oak, one of poplar, two of birch and one of hemlock species (functional diversity of 3.7). It should therefore be obvious that a forest composed of 10 tree species representing a great diversity of functional traits, and present in equal proportions of species, is better "equipped" to either resist or recover quickly and efficiently when faced with an array of known or unknown disturbances. We often make the analogy between the benefit of having a diversified financial portfolio and that of a diversified woodlot: a portfolio (a woodlot) containing investments in securities (tree species) with different characteristics (functional traits) makes it possible to minimize the risks of a sudden drop in one of these securities (loss of one or a few species caused by drought or an exotic insect).

Figure 1. Some examples of important functional traits used to characterize tree species

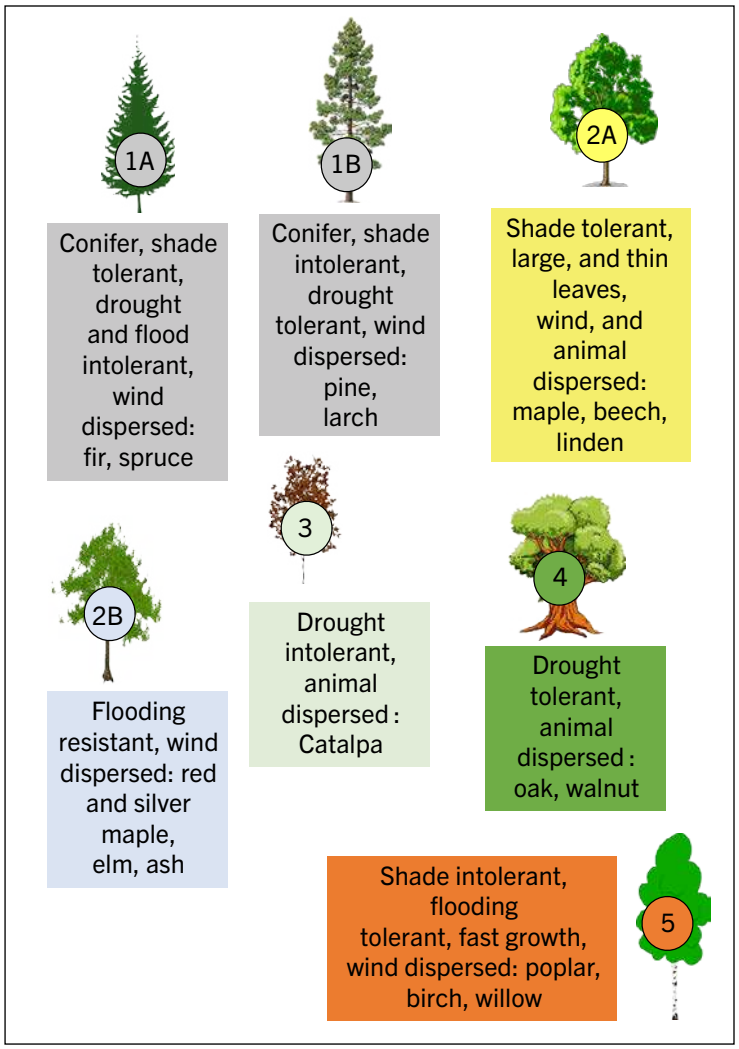


Wood density is an important trait related to drought tolerance and many other eco-physiological characteristics. Seed size is an important trait related to the ability of tree species to disperse away from the adult. The ratio of leaf area to weight is an important trait related to shade tolerance and photosynthesis rate

This is why scientists have developed a new way to assess diversity based on the biological traits, or functional traits, of tree species that includes characteristics such as wood structure, specific leaf area, ability to resprout, shade and drought tolerance, etc. Functional traits refer to any morphological (maximum tree height, seed size, root depth), physiological (photosynthesis rate, sensitivity to cavitation, drought tolerance, rejection capacity), or phenological (onset and end of annual growing season) feature that characterizes the way organisms deal with resources and conditions to grow, survive, and reproduce. These functional traits tell us how trees will respond and adapt to stress in the environment such as drought, fire, wind, flooding and grazing. A resilient forest is composed of tree species with diverse functional traits (Figure 1) so that it can withstand or adapt to the widest possible spectrum of stress. This functional trait approach thus allows us to measure this diversity and the resilience of within your woodlot.

A simple way to apply this approach in your management plan is to cluster tree species based on their similar functional traits, creating what we call functional groups (Figure 2). Thus, shade-tolerant hardwood species with high wood density and large seed size will be included in the same group, while shade-intolerant hardwood species with low wood density and small seed size will form a different functional group. In your woodlot, it is therefore important to have tree species covering the widest possible range of functional groups in more or less equal proportions to be better prepared to face a wide variety of present and future known and unknown threats.

Figure 2. Classification of tree species according to their functional similarity into five major functional groups and sub-groups (1A,1B, 2A, 2B, 3, 4, 5).



MORE CONCRETELY, WHAT TO DO IN YOUR WOODLOT?

With an inventory of the trees in your woodlot, you can determine the current dominance of particular tree species, and the proportion of different species present. From this you can see what species fall into different functional groups and therefore what species need to be maintained, increased, or decreased. You could then develop a master plan so that each time a tree is added, you ensure that it contributes to increasing the diversity and resilience of your forest. Such an increase can be achieved by selecting species from different functional groups, with an emphasis on those groups that are currently under-represented, and by ensuring that trees are evenly distributed amongst all functional groups. Your master plan should refer to your entire woodlot, creating a network of stands with high functional diversity (increase your functional connectivity: see Messier et al. 2019) that will act as sources of seeds to naturally regenerate surrounding forests after any possible disturbances to recover with better adapted tree species.

Let us take a hypothetical example of two sugar groves as described in Table 1. Sugar grove (A) has been intensively managed to produce maple syrup for a long time. It is largely dominated by sugar maple and to a lesser extent by red maple (equitability index: 0.1). Sugar grove (B) is a maple grove, possibly developed for wood production, and sugar maple is

less dominant (equitability index: 0.3). In both cases, we find the same 10 species of trees; however, since maple grove (B) has greater species equitability, it is more diversified (see Table 2). Due to the great dominance of the maple genus, maple grove (A) is in fact not very resilient and therefore susceptible to a disturbance that could affect maple trees. Although maple grove (B) is more diversified in terms of its equitability index than maple grove (A), the functional diversity index of maple grove (B) remains relatively low (see Table 2) because it lacks species from functional groups 1B (drought tolerant conifers) and 4 (drought tolerant large hardwoods) (see Table 1 and Figure 2). In other words, drought tolerant species are poorly represented, and this makes maple grove (B) not very resilient to a prolonged period of drought.

Table 1. Comparison of tree species, their functional group, and their proportion in maple grove (A) and maple grove (B), and recommendations to maintain, increase, or decrease each species to increase functional diversity (FD).

Species present	Functional group (figure 2)	Maple grove (A) with weak FD before intervention		Maple grove (B) with moderate FD before intervention	
		Proportion of species before intervention	Recommendations to increase FD	Proportion of species before intervention	Recommendations to increase FD
Fir	1A	1%	Maintain at 1%	5%	Decrease to 2.5%
White spruce	1A	1%	Maintain at 1%	2.5%	Decrease to 2.5%
White pine	1B	1%	Increase to 5%	2.5%	Increase to 10%
Sugar maple	2A	75%	Decrease to 50%	35%	Decrease to 25%
Red maple	2B	20%	Decrease to 10%	10%	Decrease to 5%
Linden	2A	<1%	Increase to 5%	10%	Maintain at 10%
Black cherry	3B	(<1%)	Increase to 5%	10%	Maintain at 10%
Red oak	4	(<1%)	Increase to 5%	(<1%)	Increase to 10%
Large-tooth aspen	5	(<1%)	Increase to 2.5%	5%	Maintain at 5%
White birch	5	(<1%)	Increase to 2.5%	10%	Decrease to 5%
Bur oak	4	0%	Increase to 2.5%	0%	Increase to 5%
Bitternut Hickory	4	0%	Increase to 2.5%	0%	Increase to 5%

Changes in species composition can be made through silvicultural interventions aimed at naturally regenerating a species already present or by planting tree species not currently present (species highlighted in grey at the bottom of the table).

Table 2. Indices of functional diversity (FD) before and after intervention recommendations in maple groves (A) and (B).

Diversity Index	Maple grove (A)		Maple grove (B)	
	Before intervention	After intervention	Before intervention	After intervention
Number of species	10	12	10	12
Equitability	0.1	0.3	0.3	0.6
Functional diversity	1.1	2.3	1.9	3.3

It is therefore clear that the functional diversity of these two types of maple groves must be increased to make them more resilient to known and unknown, present, and future disturbances. From this perspective, Table 1 presents a possible example of silvicultural interventions that could be undertaken to intelligently diversify the two types of maple groves. In the case of maple grove (A), the proposed intervention would reduce the proportion of maple, and therefore the maple production capacity, increase the proportion of other species, and add two new species from functional group 4 thereby increasing the functional diversity of the forest. In the case of maple grove (B), the proposed intervention is less drastic, involving planting two new species also from functional group 4 that are not present, resulting in a better equitability index and greater functional diversity. In both cases, the maple groves would be enriched through the planting of oak and hickory trees to ensure that functional group 4 (drought tolerant hardwoods) is well represented in the maple groves.

For those woodlot owners having monospecific plantations and/or wanting to establish such plantations within their forest, a similar approach could be used to determine which tree species to plant and where to increase the functional diversity and connectivity of your woodlot. You could also decide to plant a mixture of tree species to increase the resilience of your plantation and possibly its productivity due to complementarity in resource uses (see Messier et al. 2021).

ALL LIVING THINGS NEED TO ADAPT TO NEW CONDITIONS, AND TREES AND FORESTS ARE NO EXCEPTION.

A NEW TOOL FOR CALCULATING FUNCTIONAL DIVERSITY AND CONNECTIVITY TO HELP "IMMUNIZE" YOUR WOODLOT AGAINST GLOBAL CHANGE THREATS AND STRESSORS

Our team at Habitat is currently working on the development of a new tool and approach aimed at guiding managers in their planning and management. This new tool will first of all make it possible to calculate the equitability and functional diversity index of a woodlot using standard inventory data, but it will also provide spatially explicit recommendations on what to do where in your woodlot to most efficiently optimize the resilience of your woodlots using the functional complex network approach. This approach uses information on how far seeds of different tree species can disperse to calculate a functional connectivity index that allows the determination of where in your woodlot, or a larger forest landscape, interventions should be done first to increase its overall resilience.

For more technical and scientific information regarding some key concepts in this article, readers can look at the following papers:

Aquilué, A., Messier, C., Martins, K, Dumais-Lalonde, V., Mina, M. 2021. A simple-to-use management approach to boost adaptive capacity of forest to global uncertainty. Forest ecology and management, Vol 481. https://doi.org/10.1016/j.foreco.2020.118692.

Messier et al. 2021. For the sake of resilience and multifunctionality, let's diversify planted forests! Conservation Letters, e12829. https://doi.org/10.1111/conl.12829.

Messier, C. Bauhus, B., Doyon, D., Maure, F., Sousa-Silva, R., Nolet, P., Mina, M., Aquilué, N. and Puettmann, K. 2019. The functional complex network approach to foster forest resilience to global changes. Forest Ecosystems. 6:2. doi.org/10.1186/s40663-019-0166-2.

HOW TO ADAPT

WHAT WOODLOT OWNERS CAN EXPECT FROM CLIMATE CHANGE AND HOW THEY MIGHT ADAPT

By Steve Colombo, EcoView Consulting, Southwest Chapter

INTRODUCTION

Rapid changes in earth's climate are increasing the severity and frequency of extreme high temperatures, droughts, high winds, and outbursts of precipitation that cause flooding and ice storms. These factors stress trees, and they are combining with the ongoing impacts from air pollution, nitrogen deposition* and invasive species of disease, plants, and insects to alter the nature of woodlots in Ontario.

WAYS THAT WOODLOTS COPE WITH CLIMATE CHANGE

Woodlots have some natural qualities that allow them to tolerate changes in climate, through plasticity**, diversity, and genetic adaptation:

- Trees in woodlots have a better capacity to coexist with climate change if they have higher "plasticity," which means they tolerate a larger range of temperatures and soil moisture levels. Generally, you can spot a species with high plasticity because it is found on a wider range of site types and has a larger geographic range. The long lives of trees get in the way of natural selection that would produce a better adapted woodlot, so plasticity is important as a short-term way some tree species cope with changing climate.
- Diversity helps woodlots because it makes it more likely that some of the trees present will be able to better tolerate changed climate. Diversity within a species is called genetic diversity. Diversity can also be at the genus (e.g., maple, birch, spruce, etc.) and species levels (e.g., red maple, silver maple, sugar maple).
- Genetic adaptation is the inheritance of traits that increase the ability to cope with climate change. This adaptation can either be through changes in DNA by natural selection of regenerating trees, or by non-genetic inheritance through what are called epigenetic effects. Genetic (DNA) adaptation occurs when a stress favours the survival of trees with helpful traits. Non-genetic inheritance happens when a stress affecting the parent(s) affects the pollen and/or the ovule in the female flower, passing on increased stress tolerance to the offspring for multiple generations but without altering DNA. The advantage of non-genetic inheritance is that it can alter stress tolerance for a larger share of the offspring than genetic selection.

** Nitrogen Deposition: the input of reactive nitrogen from the atmosphere to the biosphere both as gases, dry deposition and in precipitation as wet deposition.*

*** Plasticity: the adaptability of an organism to changes in its environment or differences between its various habitats.*

The author with his faithful pooch Loki.

Each of these mechanisms can affect how trees are able to tolerate the stresses caused by climate change. And some of these mechanisms influence a number of the approaches that are used to identify which species are potentially more vulnerable than others as climate change becomes increasingly challenging.

HOW VULNERABLE IS YOUR WOODLOT TO CLIMATE CHANGE?

Over 130 tree species are native to Ontario, some tolerate relatively wide variations in environment – they have higher plasticity – others that have lower plasticity thrive in a narrower range of conditions.

Each species has specific and slightly different environmental requirements that must be met for successful establishment, growth, and reproduction. In general, trees growing near the southern end of their natural range will be negatively affected by increasing temperatures, because they are likely already growing at temperatures warmer than are optimum. The reverse can also be true as some species at the northern end of their natural range will perform better as temperatures rise, because they are likely growing at temperatures colder than their optimum. However, species at the northern edge of their climatic range may not perform as well with climate change if they are drought-sensitive. Increased drought in some areas is expected with climate warming where precipitation does not increase enough to replace the soil moisture losses caused by warmer temperatures.

People who manage trees are often interested in how the species found in their area will be affected by climate change. Several approaches have been developed that give clues as to which species will do best with climate change, and which will fare less well. These approaches fall into five categories:

i. Expert opinion – expert opinion uses input from people with knowledge related to local forests – these could be landowners, forestry professionals or scientists. This approach can give a quick assessment of the risks posed by climate change to a species or to a particular forest area.

ii. Retrospective analysis – historical responses to past weather extremes can tell us how species may fare as those extremes intensify.

iii. Forest condition and species life traits – these are descriptions of species in terms of factors affecting their ecological behaviour. Some examples are sensitivity to stresses (e.g., drought, waterlogging, ice damage), species rarity and population isolation, seed production, disease risk, natural regeneration mechanisms, etc.

iv. Climate envelope modelling – the climate envelope describes an area with the temperature, moisture, etc., to which a species is adapted. Comparing future climate with a species' climate envelope can in theory tell us when, or if, a species will be beyond its perceived envelope, and possibly exposed to climatic stresses. Climate envelopes do not tell us when the disequilibrium becomes too great for a species to survive or reproduce.

v. Physiological models – predictions of changes in forest growth, regeneration and changes in species composition can be done by modelling tree physiological and ecosystem processes over years and decades. The result is a projection of what the future forest might look like, considering factors such as temperature, precipitation, and elevated CO2.

Here I have combined two of these approaches — climate envelope and a species life trait — to provide an indication of the vulnerability of a number of southern Ontario species to climate change. Climatic envelope modelling in this example simply describes whether a species' recent historical climate range lies at the southern edge of latitude 44°N, or in the middle or south of this latitude. The life trait evaluated was species drought sensitivity.

44°N was chosen because it is roughly on a median north-south position in southern Ontario running east to west between Grand Bend and Kingston.

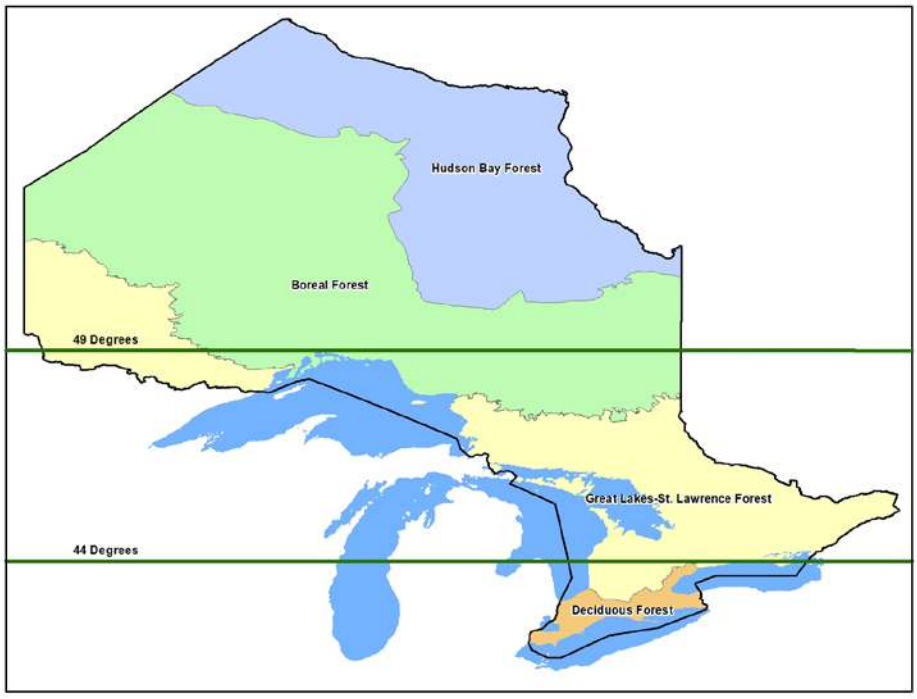


Table 1 divides species found in Ontario based on their climate envelope and drought sensitivity. Species are categorized into groups that are currently near the southern edge, the middle, or the northern edge of their climate envelope, relative to 44°N. These species groups are further broken down based on sensitivity to drought – with moderate to low sensitivity combined into one classification and high sensitivity to drought into another.

The assessment in the following table is an example of how species may differ in vulnerability to climate change. In general, those near the middle of their natural range or at the northern edge of that range, and that have moderate to low sensitivity to drought, may be less vulnerable to climate change. In comparison, those at the southern edge of their range and that are highly sensitive to drought may be most vulnerable.

Southern Range Edge (likely more vulnerable to climate change)	**Middle of Range (likely moderately vulnerable to climate change)**	**Northern Range Edge (likely less vulnerable to climate change)**
Moderate or Low Sensitivity to Drought		
Cornus stolonifera – Red osier dogwood	*Acer negundo* – Manitoba maple	*Aesculus glabra* – Ohio buckeye
Picea glauca - White spruce	*Acer platanoides* – Norway maple (NN)[3]	*Carya coridformus* – Bitternut hickory
Rhus typhina – Staghorn sumac	*Acer rubrum* – Red maple	*Carya ovata* – Shagbark hickory
Taxus canadensis – Canada yew	*Acer saccharinum* – Silver maple	*Catalpa speciosa* – Northern catalpa
Thuja occidentalis – Easter white cedar	*Acer saccharum* – Sugar maple	*Celtis occidentalis* – Northern hackberry
Ulmus americana - White elm	*Fraxinus americana* – White ash	*Crataegus mollis* – Downy hawthorn
	Ostrya virginiana – Ironwood	*Crataegus punctata* – Dotted hawthorn
	Pinus resinosa - Red pine	*Gleditsia triacanthos* – Honey locust
	Pinus strobus - White pine	*Gymnocladus dioicus* – Kentucky coffeetree
	Populus grandidentata - Largetooth aspen	*Juglans nigra* – Black walnut
	Populus tremuloides - Trembling aspen	*Juniperus virginiana* – Easter red cedar
	Prunus virginiana – Chokecherry	*Liquidambar styraciflua* – Sweetgum
	Quercus alba – White oak	*Maclura pomifera* – Osage orange (NN)
	Quercus macrocarpa – Bur oak	*Morus alba* – White mulberry (NN)
	Quercus rubra – Red oak	*Nyssa sylvatica* – Black gum
	Rhus glabra – Smooth sumac	*Platanus occidentalis* – American sycamore
	Tilia americana - Basswood	*Populus deltoides* – Eastern cottonwood
	Acer rubrum – Red maple	*Prunus serotina* – Black cherry
	Acer saccharinum - Silver maple	*Ptelea trifoliata* – Common hoptree
		Quercus bicolor – Swamp white oak
		Quercus coccinea – Scarlet oak
		Quercus muehlenbergii – Chinquapin oak
		Quercus palustris – Pin oak
		Quercus shumardii – Shumard oak
		Quercus velutina – Black oak
		Sassafras albidum – Sassafras
		Ulmus rubra – Slippery elm
		Ulmus thomasii – Rock elm
High Sensitivity to Drought		
Abies balsamea – Balsam fir	*Betula alleghaniensis* – Yellow birch	*Asimina triloba* – Pawpaw
Betula papyrifera – White birch	*Carpinus caroliniana* – Ironwood	*Cercis canadensis* – Redbud
Larix laricina – Tamarac	*Cornus alternifolia* – Alternate-leaf dogwood	*Cornus florida* – Flowering dogwood
Sorbus americana – American mountain ash	*Fagus grandifolia* – American beech	*Juglans cinerea* – Butternut
Sorbus decora – Showy mountain ash	*Salix amygdaloides* – Peachleaf willow	*Liriodendron tulipifera* – Tulip tree
	Tsuga canadensis – Eastern hemlock	*Magnolia acuminata* – Cucumbertree
		Morus rubra – Red mulberry
		Salix alba – White willow (NN)
		Salix nigra – Black willow

[1] Species climatic envelope is from Natural Resources Canada's Plant Hardiness website (http://www.planthardiness.gc.ca/index.pl?lang=en&m=7m&speciesid=1000329). To assign a species to a range category, species MaxEnt maps were visually evaluated and rated according to whether a line at roughly 44°N latitude was near the middle, northern edge, or southern edge of the climate range for the period 1970-2000.

[2] Drought sensitivity was obtained from Vineland Research Station's online Tree Species Selector tool at https://www.greeningcanadianlandscape.ca/tree-species-selector/eastern-canada-tree-species# (no longer accessible) and the Morton Arboretum online species descriptions at https://www.mortonarb.org/trees-plants/tree-and-plant-selection.

[3] Non-native species

TREES NEAR THE MIDDLE OF THEIR NATURAL RANGE OR AT THE NORTHERN EDGE OF THAT RANGE, AND THAT HAVE MODERATE TO LOW SENSITIVITY TO DROUGHT, MAY BE LESS VULNERABLE TO CLIMATE CHANGE

CONCLUSIONS

While uncertainty about the pace of climate change and about how species may respond to it might make some people hesitant to consider adapting their woodlots to climate change, no-regrets management options provide benefits for the woodlot regardless of climate change and often helps the woodlot both now and in future as the climate changes.

Some no-regrets management actions are as follows:

i. The first and most important principle to follow is to practice good woodlot management. Support by trained and certified forestry experts provides woodlot owners with management practices that protect and improve woodlot health, which can increase the resilience of woodlots against all types of stresses, including those from climate change.

ii. Increase woodlot diversity at the genus, species, and genetic levels. The more diverse the woodlot, the more likely it will be that some genus, species, or individuals will be able to cope with increasing climatic stresses, extreme weather events, and either invasive or climatically invigorated native insect pests and diseases.

   a. When considering increasing diversity, keep in mind species that have good drought tolerance and whose range is either partly or mostly south of the location of the woodlot.

   b. If planting trees, document the source of the seed (information the nursery may know) and document the survival and growth of the seedlings. Plant using a mixture of species and a mix of genetic sources.

iii. Allow opportunities for trees to regenerate within a woodlot. Depending on the environmental conditions prior to and during regeneration, some of the progeny may be selected genetically for improved performance or may have multi-generational benefits from non-genetic inheritance.

iv. Document what is happening in your woodlot to help guide future management actions. For example, are trees being damaged by climatic or extreme weather events; when do trees of different species resume growth: are species experiencing dieback or mortality?

Woodlots can be an important source of information, from which landowners, foresters and scientists can evaluate the responses of species to climate change. Such information can provide baseline knowledge needed to take adaptive actions to maintain woodlot health and sustainability. A long-term commitment to collecting and using such information and to implement adaptive management in woodlots can pay long-term dividends. The role of helping to collect this data and information is suitable for government because, even though woodlots are owned privately, they are an important resource that provides all the province with numerous ecological, economic, and social benefits.