Climate Change-Resilience in the Acadian Forest: A Review

February 2018

by Megan de Graaf, MScF
Forest Ecologist
Community Forests International

Funded by

New Nouveau Brunswick
Your Environmental Trust Fund at Work
Votre Fonds en fiducie pour l'environnement au travail

Table of Contents

Executive Summary

The Acadian Forest Region (AFR), which is comprised of boreal tree species and more southerly-affiliated tree species to form a unique mixed forest type, is widely considered to have been simplified, degraded, and borealized through decades (even centuries) of intensive forest management. Results from three recent research projects into the resilience of this forest type, and its constituent tree species, to the effects of climate change have come to some consensus: that only nine species will likely persevere in the long-term (2011-2100): eastern hemlock, eastern white cedar, red maple, red oak, red spruce, sugar maple, white ash, white pine, and yellow birch. Of those species, only four are likely to increase in growth and distribution: red maple, red oak, white ash, and white pine. Another fourteen species were identified by one or two (but not all three) of the research projects as having moderate to high resilience to climate change: American beech, American mountain ash, balsam poplar, black cherry, bur oak, butternut, ironwood, mountain maple, mountain paper birch, pin cherry, serviceberry, silver maple, striped maple, and white elm.

Some compelling results have also come from research into landscape-level resilience to climate change. From these results, we can see spatially across southeastern NB the pattern of decline to proliferation of species and forest stands, and identify which stands will experience the most change. Worrisomely, and likely due to decades of intensive borealization of the Acadian forest, there is a high percentage of stands in the region that are predicted to decline or merely persevere in the mid-term (2041-2070). Combining this data from stand- and landscape-level resilience analyses, along with landscape resilience data from other conservation organizations, has generated maps of landscape corridors that should be prioritized for on-the-ground conservation and adaptation action.

From these results, two clear avenues of action arise:

1. Climate-adaptive silviculture: much needed is a suite of silviculture prescriptions that manage the forests composition to become more diverse and more resilient to climate change (i.e. adaptation), and these prescriptions are needed for a variety of stand ages and conditions; and,
2. Widespread forest conservation, strategic corridors: it is critical to pull as many forested lands out of the industrial forestry process as possible. What few remaining stands of mixed old Acadian forest need to be protected and managed for long-term resilience, and younger stands need to be replanted and/or managed for long-term resilience. Strategically, focusing on protecting lands within the habitat connectivity corridors should take first priority.

Introduction

Decades of industrial forest management in the Acadian Forest Region (AFR) have increasingly simplified, degraded, and borealized the forest. The climate in this region is projected to, in general terms, become warmer and wetter, and with increasing disturbance events. These changes are predicted to have serious consequences for the long-term survival of tree species and for the persistence of functioning, healthy forest in the AFR.

In the last decade or so, three research groups in New Brunswick have investigated the climate change-resilience of 32 tree species native to the AFR. These three groups have published/released their research results in the last decade, and this document summarizes them here and presents common conclusions. This document also reviews local research into landscape-level forest resilience and projected resilient and non-resilient forest patches, as well as potential corridors of resilient habitat.

Tree Species' Resilience

Establishing the resilience of individual tree species to climate change is critical for conservation planning, forest management, and successfully adapting to climate change. The unique characteristics of the AFR and its tree species' resilience to climate change is well described by Taylor *et al.* (2017; references within):

> Eastern Canada's Acadian Forest Region is part of an ecological transition zone occurring along the United States–Canada border area that links conifer-dominated boreal forest to the north with temperate deciduous forests to the south. Such transition zones are considered particularly susceptible to changes in tree species growth and other drivers of stand-level competition because many species that coexist in these ecosystems are close to their extreme southern or northern climatic limits. Climate-driven influences on competitive interactions are expected to cause changes in forest composition; for example, cold-adapted boreal conifers, such as balsam fir (*Abies balsamea* L.) and black spruce (*Picea mariana* (Mill.) B.S.P.), which are currently at their southern limit in the Acadian Forest, are likely to compete poorly under a warming climate, decreasing in both growth and abundance. Conversely, temperate species, such as red maple (*Acer rubrum* L.) and red oak (*Quercus rubra* L.), are expected to benefit from warming, allowing them to compete more successfully. This could potentially cause a shift in the overall composition of the Acadian Forest toward dominance by temperate species. Even though temperate species can be expected to perform better in a warmer regional climate, the overall growth of the Acadian Forest may still decrease for some period because the rate of climate change projected for the 21st century will likely outpace the ability of southern species to colonize newly available sites and offset decreases in growth from the loss of cold-adapted boreal species.

In the last decade or so, three research groups in New Brunswick have investigated climate change-resilience of the 32 tree species native to the AFR: the Fundy Biosphere Reserve (fundy-biosphere.ca), Charles P.-A. Bourque and Quazi K. Hassan (University of New Brunswick), and Anthony Taylor *et al.* (a team of researchers from the Canadian Forest Service and UNB).

The findings of each of these three groups is summarized below.

Fundy Biosphere Reserve, 2013- 2016

The Fundy Biosphere Reserve (FBR) analysed downscaled models from Canada's Plant Hardiness website, maintained by Natural Resources Canada, which contains the bioclimatic profiles and climate envelope maps for 130 tree species based on known tree species distributions (Fundy Biosphere Reserve, 2015). Climate change will cause these climate envelopes to fluctuate at first, then migrate later. Trees living close to the edge of their climate envelopes will experience more frequent, and eventually permanent, shifts of climate conditions.

> A climate envelope refers to the set of climatic conditions that each tree species can tolerate. A species' climate envelope could also be thought of as its geographic range of growing conditions.

The climate envelope maps cover three future time periods including 2011 -2040, 2041-2070, and 2071-2100. To predict expected changes in temperature over the 2011-2100 period of interest, the FBR chose to use the radiative forcing scenario RCP 4.5 (which would produce a 2.4°C median temperature anomaly over pre-industrial levels by 2100) as a moderate climate change future. For a comparison of the different climate change models used by the research projects described in this document, see Appendix I.

> Radiative Forcing (RF) is the measurement of the capacity of a gas or other forcing agents to affect that energy balance, thereby contributing to climate change - put more simply, RF expresses the change in energy in the atmosphere due to GHG emissions. Radiative forcing scenarios, therefore, depict differing climate warming scenarios, based on the intensity of actions taken to mitigate climate change.

The FBR downloaded climate envelope maps from Natural Resources Canada covering the current range of each tree species selected for analysis under the three future time periods modeled. Each species was ranked by their relative response to climate change across the three future time periods: proliferate, prosper, persevere, decline, and disappear. A qualification of 'proliferate' suggests that a particular species will maintain a generally healthy population in 2041-2070, staying relatively free of major disturbance. The second category (prosper) generally suggests future health with perhaps sporadic disturbance. The middle category (persevere) suggests uncertainty, with tree species facing either no disturbance, periods of disturbance or major continued disturbance. The fourth category (decline) suggests higher chance of periodic disturbance or continued disturbance in some cases. The fifth category (disappear) suggests possible continued disturbance or even major catastrophic disturbance removing the species from the landscape. For more detailed description of methods, see the FBR's 2015 technical paper (Appendix II).

Table 1. The tree species resiliency for the **2041-2070** time period for a moderate climate change scenario (RCP 4.5). The five categories contain tree species with resiliency rankings falling under the values displayed in the column headers. During this time period, no species fell into the "Disappear" category. Tree species marked with an asterisk (*) are products of post-disease breeding programs meant for reintroduction. Disturbance may strike particular species harder than conservative estimates in this report; therefore species such as butternut may be placed in a higher resiliency category than expected. Species in grey text are non-natives from southern Maine.

Proliferate 10 to 6.1	Prosper 6 to 2.1	Persevere 2 to -2	Decline 2.1 to -6	Disappear 6.1 to -10
American Beech - *Fagus grandifolia*	Eastern Hemlock - *Tsuga canadensis*	Eastern Larch - *Larix laricina*	Balsam Fir - *Abies balsamea*	
Black Cherry - *Prunus serotina*	White pine - *Pinus strobus*	Eastern White Cedar - *Thuja occidentalis*	Black spruce - *Picea mariana*	
Ironwood - *Ostrya virginiana*	Butternut - *Juglans cinerea*	Red pine - *Pinus resinosa*	Jack pine - *Pinus banksiana*	
Red Maple - *Acer rubrum*	Mountain paper Birch - *Betula cordifolia*	American Basswood - *Tilia americana*	Red spruce - *Picea rubens*	
Atlantic White Cedar - *Chamaecyparis thyoides*	Red Oak - *Quercus rubra*	American Mountain Ash - *Sorbus americana*	White spruce - *Picea glauca*	
Pitch Pine - *Pinus rigida*	Sugar Maple - *Acer saccharum*	Balsam Poplar - *Populus balsamifera*	Black Ash - *Fraxinus nigra*	
Black Oak - *Quercus velutina*	White Ash - *Fraxinus americana*	Black Willow - *Salix nigra*	Grey Birch - *Betula populifolia*	
Blue Beech - *Carpinus caroliniana*	*White Elm - *Ulmus americana*	Bur Oak - *Quercus macrocarpa*	Large Toothed Aspen - *Populus grandidentata*	
Sassafras - *Sassafras albidum*	Eastern Red Cedar - *Juniperus virginiana*	Choke Cherry - *Prunus virginiana*	Silver Maple - *Acer saccharinum*	
White oak - *Quercus alba*	*American chestnut - *Castanea dentata*	Mountain Maple - *Acer spicatum*	Trembling Aspen - *Populus tremuloides*	
	American Sycamore - *Platanus occidentalis*	Pin Cherry - *Prunus pensylvanica*	White Birch - *Betula papyrifia*	
	Bitternut Hickory - *Carya cordiformis*	Serviceberry - *Amelanchier canadensis*	Yellow Birch - *Betula allenghaniensis*	
	Red Elm - *Ulmus rubra*	Striped Maple - *Acer pensylvanicum*	Black Maple - *Acer nigrum*	
	Scarlet Oak - *Quercus coccinea*	Staghorn Sumac - *Rhus typhina*	Swamp White Oak- *Quercus bicolor*	

The FBR also assessed abiotic (fire and windthrow susceptibility) and biotic (animal browse, insect pests, rot and disease) threats to these same species, to expand on the climate envelope-only analyses (which are shown in Table 1). Figure 1 shows that all species are likely to exhibit slight to significantly reduced resilience once those disturbance factors are accounted for, as compared to climate envelope-only analyses. The impact on each species due to these abiotic and biotic factors is indicated in Figure 1 by the green bars, whereas the impact as a result of the climate envelope-only analysis is indicated by the white bars.

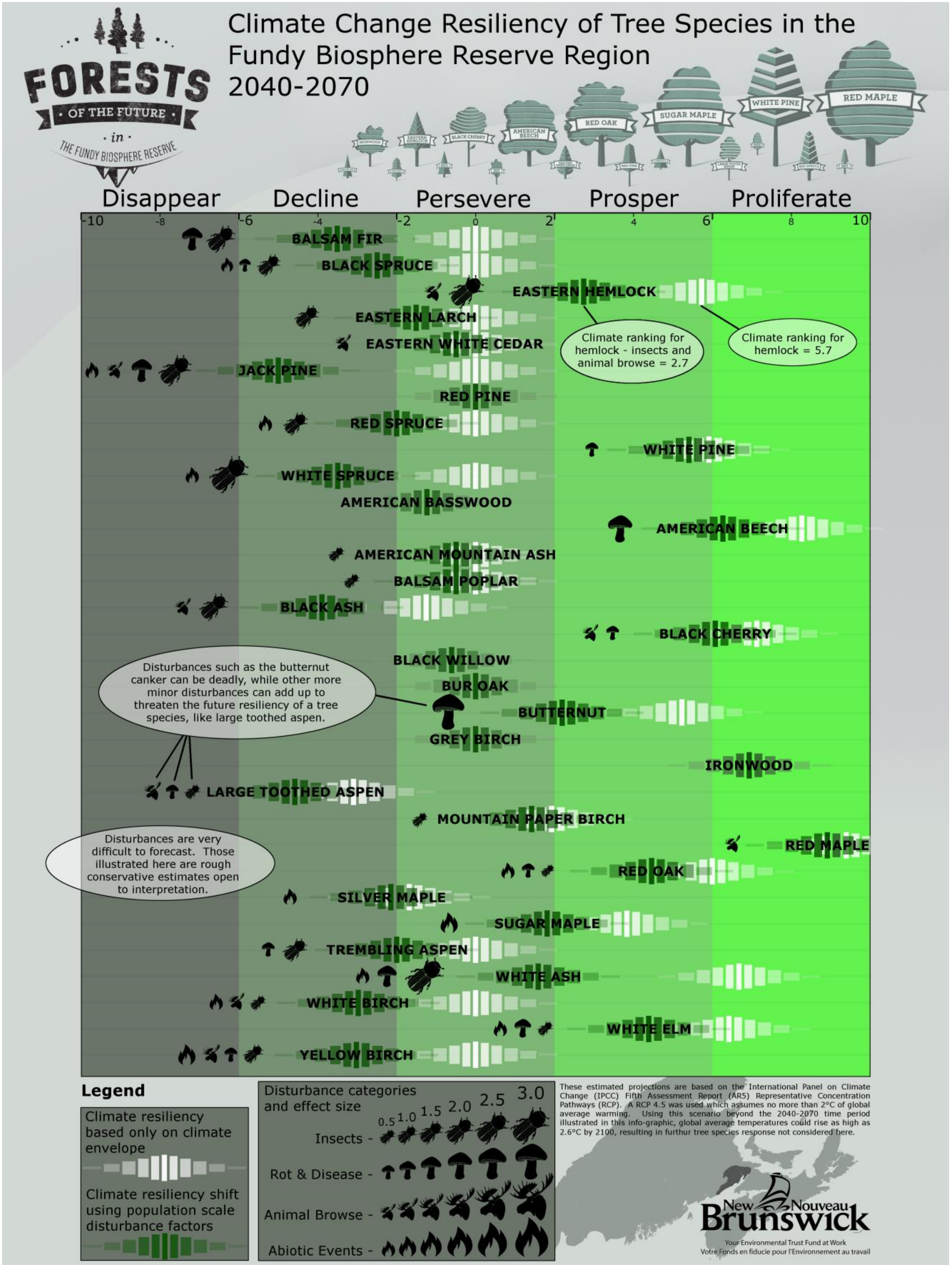


Figure 1. Projected native species resilience to climate change in 2041-2070, based on climate envelope analysis and corrected by abiotic and biotic disturbances. All species are likely to exhibit slight to enormously reduced resilience (green bars) once disturbance factors are accounted for, as compared to climate envelope-only analyses (white bars).

As a result, the FBR has identified the following species as the most likely to be resilient (prosper or proliferate) to climate change in 2041-2070 (in order from most to least resilient of the prosper and proliferate species): red maple; ironwood; American beech; black cherry; white pine; red oak; white (American) elm; eastern hemlock; butternut; sugar maple; white ash; and mountain paper birch. There are another thirteen species that will persevere in the Acadian forest during that time frame, but are likely to eventually decline by the end of the century: black spruce; eastern larch; eastern white cedar; red pine; red spruce; American basswood; American mountain ash; balsam poplar; black willow; bur oak; grey birch; silver maple; and trembling aspen.

Bourque & Hassan, 2010

Dr. Charles Bourque, from the University of New Brunswick, and his colleague Dr. Quazi K. Hassan, published some first results in 2008 about the projected impacts of climate change on species distribution in the Acadian forest of eastern Nova Scotia (Bourque & Hassan, 2008). They then produced much more detailed projections for the government of Prince Edward Island in 2010 (Bourque & Hassan, 2010). The AFR includes PEI, as well as NB and NS, and although there are somewhat different climactic conditions on the island, many changes to the climate will be similar among the three Maritime provinces.

To summarise the PEI report, Bourque and Hassan modeled changes to the climate and to thirteen tree species distributions as a result of those climatic changes.

The thirteen species investigated include

i. seven softwood species: white spruce (*Picea glauca* (Moench) Voss), white pine (*Pinus strobus* L.), eastern white cedar (*Thuja occidentalis* L.), eastern hemlock (*Tsuga Canadensis* (L.) Carr.), balsam fir (*Abies balsamea* (L.) Mill.), red pine (*Pinus resinosa* Ait.), and red spruce (*Picea rubens* Sarg.); and

ii. six hardwood species: white ash (*Fraxinus americana* L.), yellow birch (*Betula alleghaniensis* Britton), white birch (*Betula papyrifera* Marsh.), sugar maple (*Acer saccharum* Marsh.), red maple (*Acer rubrum* L.), and red oak (*Quercus rubra* L.).

The climate change scenarios for PEI were based on Environment Canada's Canadian Coupled Global Climate Model (CCGCM1), using a "business as usual" (conservative) greenhouse gas emission scenario (i.e., IS92a scenario; see Appendix I for comparisons to other models). That scenario assumes very little action toward mitigating climate change, which would yield a 4.9°C median temperature anomaly over pre-industrial levels by 2100. Under that scenario, Bourque & Hassan modeled species' distribution changes for current climatic conditions (1971-2000) and for three future conditions (2011-2040, 2041-2070, and 2071-2100). For a more detailed description of methods, see Bourque & Hassan's full 2010 technical paper in Appendix III.

Over the full span of nearly 100 years (2011-2100), they found that the distributions of the thirteen species changed remarkably (Table 2). Figure 2 shows a sample result for white pine, where its distribution is modeled for the current and three future time periods.

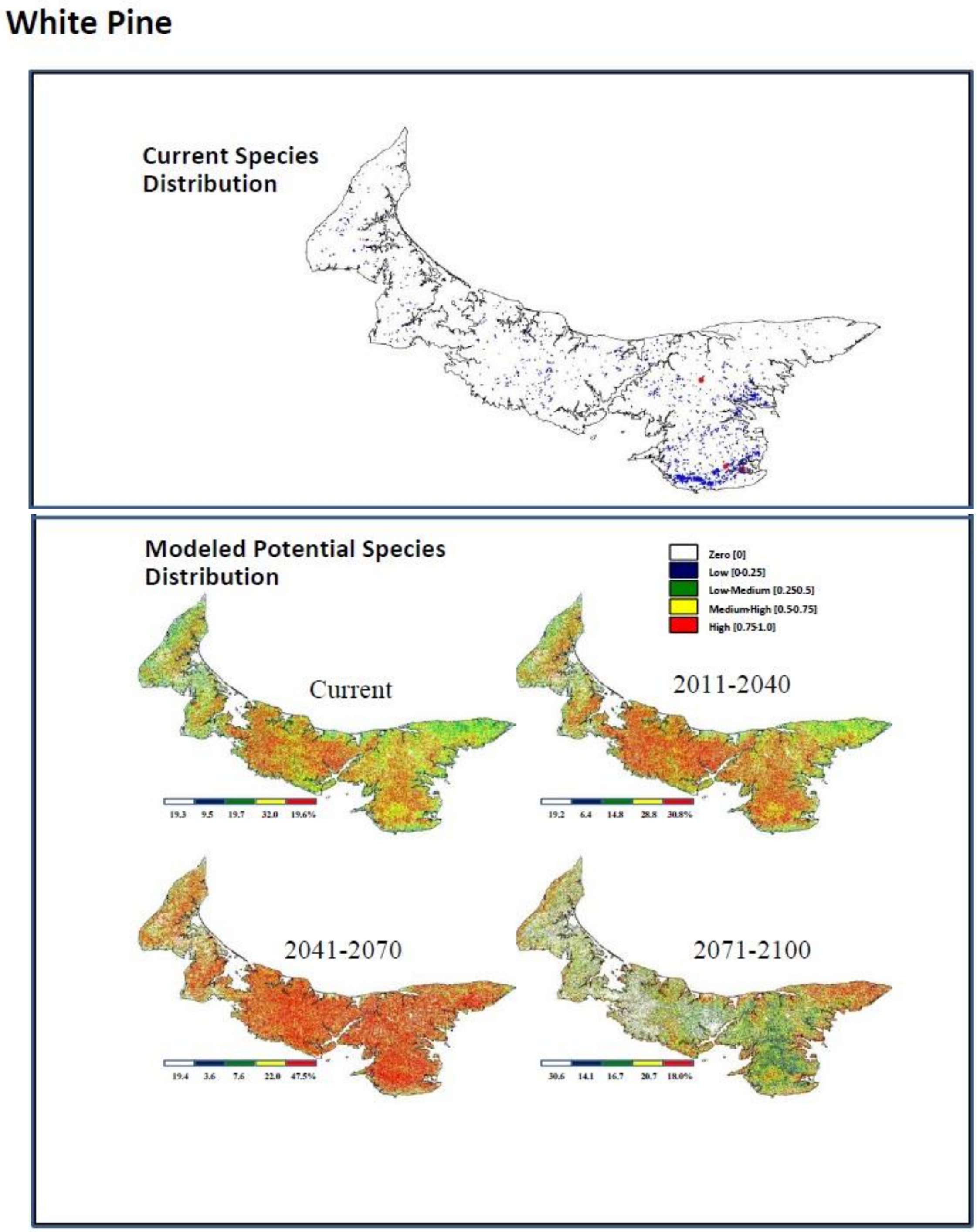


Figure 2. White pine distribution across Prince Edward Island (PEI) as modeled by Bourque & Hassan (2010) using a conservative (IS92a) GHG emissions scenario, for the current and three future time periods.

For easy comparison, their projections for species changes in 2011-2100 are translated into the relative resiliency rankings (i.e. decline to proliferate) used by the FBR (Table 2).

Table 2. Modeled distribution changes of thirteen native Acadian Forest Region tree species from 2011-2100, as compared to the current climactic conditions (1971-2000). The right column describes the same results using rankings used by the Fundy Biosphere Reserve (FBR).

Native Tree Species	**2011-2100**	**FBR terms**
Balsam Fir (*Abies balsamea*)	Decrease	Decline
Eastern hemlock (*Tsuga canadensis*)	Increase, then decrease	Persevere
Eastern white cedar (*Thuja occidentalis*)	Decrease	Decline
Red maple (*Acer rubrum*)	Increase	Proliferate
Red oak (*Quercus rubra*)	Increase	Proliferate
Red pine (*Pinus resinosa*)	Decrease	Decline
Red spruce (*Picea rubens*)	Decrease	Persevere
Sugar maple (*Acer saccharum*)	Stable, then decrease	Persevere
White ash (*Fraxinus americana*)	Increase	Proliferate
White birch (*Betula papyrifera*)	Decrease	Decline
White pine (*Pinus strobus*)	Increase, then decrease	Prosper
White spruce (*Picea glauca*)	Decrease	Decline
Yellow birch (*Betula alleghaniensis*)	Increase, then decrease	Persevere

Taylor *et. al.*, 2017

Taylor *et al.* (2017) used a well-established forest ecosystem simulation model, PICUS, to explore the impact of climate change on the composition and growth of the Acadian Forest Region for the period 2011 to 2100 under two warming scenarios: RCP 2.6; and RCP 8.5. The authors chose these two scenarios to contrast two very different climate futures: the "business-as-usual" high radiative forcing scenario (RCP 8.5), where greenhouse gas emissions continue to rise without any attempted reductions and will generate approximately a 4.9°C median temperature anomaly over pre-industrial levels by 2100, and RCP 2.6 (the low forcing scenario), which represents a lower rate of climate change due to strong and immediate reductions in emissions and will still produce 1.5°C median temperature anomaly over pre-industrial levels by 2100.

Taylor et al. (2017) modeled 18 native tree species and the authors predict little change in the short term relative to current conditions; however, over the medium- to long-terms, changes became more significant as predicted by PICUS. Generally, by the end of the century, the authors predict that five species will increase in relative abundance (American beech, red maple, red oak, white ash, and white pine) and that ten species will decrease (balsam fir, black spruce, eastern larch, jack pine, red pine, red spruce, sugar maple trembling aspen, white spruce, and white birch; Table 3). There are a couple of caveats, though, attached to limitations in the models: the authors acknowledge that the effect of beech bark disease is likely underestimated for this region (and therefore American beech may not increase as projected), and that competition with American beech led the model to incorrectly underestimate sugar maple (which therefore may increase, rather than decrease). The projected relative abundance of three species is unclear.

Table 3. Changes in relative abundance of 18 tree species over 2011-2100. Simulations do not take into consideration the strong negative impact of beech bark disease in our region (*) and likely underestimated the overall abundance of sugar maple (**).). The right column describes the same results using rankings used by the Fundy Biosphere Reserve (FBR).

Native Tree Species	**2011-2100**	**FBR terms**
American Beech (*Fagus grandifolia*)	Increase*	Prosper
Balsam Fir (*Abies balsamea*)	Decrease	Decline
Black spruce (*Picea mariana*)	Decrease	Decline
Eastern Hemlock (*Tsuga canadensis*)	Unclear	Persevere
Eastern Larch (*Larix laricina*)	Decrease	Decline
Eastern White Cedar (*Thuja occidentalis*)	Unclear	Persevere
Jack pine (*Pinus banksiana*)	Decrease	Decline
Red Maple (*Acer rubrum*)	Increase	Prosper
Red Oak (*Quercus rubra*)	Increase	Prosper
Red pine (*Pinus resinosa*)	Decrease	Decline
Red spruce (*Picea rubens*)	Decrease	Decline
Sugar Maple (*Acer saccharum*)	Decrease**	Decline
Trembling Aspen (*Populus tremuloides*)	Decrease	Decline
White Ash (*Fraxinus americana*)	Increase	Prosper
White Birch (*Betula papyrifera*)	Decrease	Decline
White pine (*Pinus strobus*)	Increase	Prosper
White spruce (*Picea glauca*)	Decrease	Decline
Yellow Birch (*Betula allengheniensis*)	Unclear	Persevere

Areas of Consensus

Each of these three research projects used different models and climate change scenarios, using different assumptions of climate change intensity over the next 100 years. These different climate change scenarios are compared in Appendix I. Across the various models and methodologies, and looking at the long term (2011-2100), all three research projects mostly agreed on which of the thirteen species that all three projects examined would decline, persevere, prosper, or even proliferate (Table 4).

Table 4. Comparison of climate change resiliency projections from three research projects, for thirteen tree species, for 2011-2100. This estimate (*) likely underestimates the effects of beech bark disease in the region and (**) likely underestimates the overall abundance of sugar maple (see article for details).

Native Tree Species	**FBR**	**Taylor *et al.***	**Bourque & Hassan**	**Conclusion**
American Basswood (*Tilia americana*)	Decline	-	-	
American Beech (*Fagus grandifolia*)	Prosper	Increase*	-	
American Mountain Ash (*Sorbus americana*)	Persevere	-	-	
Balsam Fir (*Abies balsamea*)	Decline	Decrease	Decline	**Decline**
Balsam Poplar (*Populus balsamifera*)	Persevere	-	-	
Black Ash (*Fraxinus nigra*)	Decline	-	-	
Black Cherry (*Prunus serotina*)	Prosper	-	-	
Black spruce (*Picea mariana*)	Decline	Decrease	-	**Decline?**
Black Willow (*Salix nigra*)	Decline	-	-	
Bur Oak (*Quercus macrocarpa*)	Persevere	-	-	
Butternut (*Juglans cinerea*)	Persevere	-	-	
Eastern Hemlock (*Tsuga canadensis*)	Persevere	Unclear	Persevere	**Persevere**
Eastern Larch (*Larix laricina*)	Persevere	Decrease	-	**Unclear**
Eastern White Cedar (*Thuja occidentalis*)	Persevere	Unclear	Decline	**Isolated patches?**
Grey Birch (*Betula populifolia*)	Decline	-	-	
Ironwood (*Ostrya virginiana*)	Proliferate	-	-	
Jack pine (*Pinus banksiana*)	Disappear	Decrease	-	**Decline?**
Large Toothed Aspen (*Populus grandidentata*)	Decline	-	-	
Mountain Maple (*Acer spicatum*)	Persevere	-	-	
Mountain paper Birch (*Betula cordifolia*)	Prosper	-	-	
Pin Cherry (*Prunus pensylvanica*)	Persevere	-	-	
Red Maple (*Acer rubrum*)	Proliferate	Increase	Proliferate	**Proliferate**
Red Oak (*Quercus rubra*)	Prosper	Increase	Proliferate	**Proliferate**
Red pine (*Pinus resinosa*)	Persevere	Decrease	Decline	**Decline**
Red spruce (*Picea rubens*)	Decline	Decrease	Persevere	**Isolated patches?**
Serviceberry (*Amelanchier canadensis*)	Persevere	-	-	
Silver Maple (*Acer saccharinum*)	Persevere	-	-	
Striped Maple (*Acer pensylvanicum*)	Persevere	-	-	
Sugar Maple (*Acer saccharum*)	Persevere	Decrease**	Persevere	**Persevere**
Trembling Aspen (*Populus tremuloides*)	Persevere	Decrease	-	**Unclear**
White Ash (*Fraxinus americana*)	Persevere	Increase	Proliferate	**Prosper**
White Birch (*Betula papyrifera*)	Decline	Decrease	Decline	**Decline**
White Elm (*Ulmus americana*)	Prosper	-	-	
White pine (*Pinus strobus*)	Prosper	Increase	Prosper	**Prosper**
White spruce (*Picea glauca*)	Decline	Decrease	Decline	**Decline**
Yellow Birch (*Betula allenghaniensis*)	Decline	Unclear	Persevere	**Isolated patches?**

Landscape-Level Resilience

The resilience of individual tree species across a landscape informs forest stand resilience and therefore landscape-level resilience to climate change. A forests stand, for example, that is comprised primarily of tree species with low resilience to climate change will equally be at high risk of declining over the next 50-100 years. Little is currently known, or even projected, for how the composition of these at-risk stands will respond as individual species decline, so that understanding the changes in forest composition across a landscape and over time is even more important for developing actions to combat climate change.

To examine landscape-level resilience, the FBR mapped the forest stands, based on the proportion of species that would prosper/proliferate (high resilience) versus merely persevere or even decline (low-resilience). Figure 3 shows stands that are likely to be the least resilient (red), most resilient (blue), or simply maintain themselves (persevere; yellow) in the mid-term (2041-2070). As another way of presenting the same information, the FBR also mapped only the stands that are highly resilient to climate change (Fig. 4).

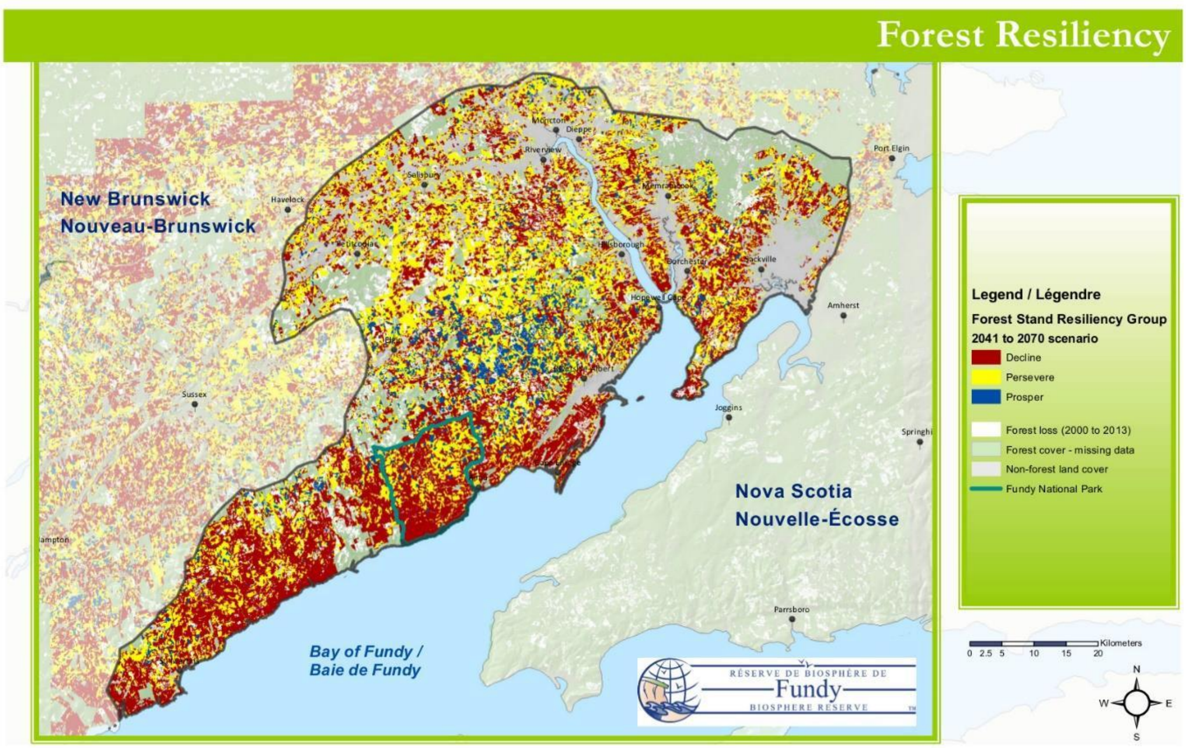


Figure 3. Forest stands that are predicted to decline (red), persevere (yellow) or prosper (blue) in the mid-term (2041-2070), based on the composition of tree species, and their predicted resilience, within those stands.

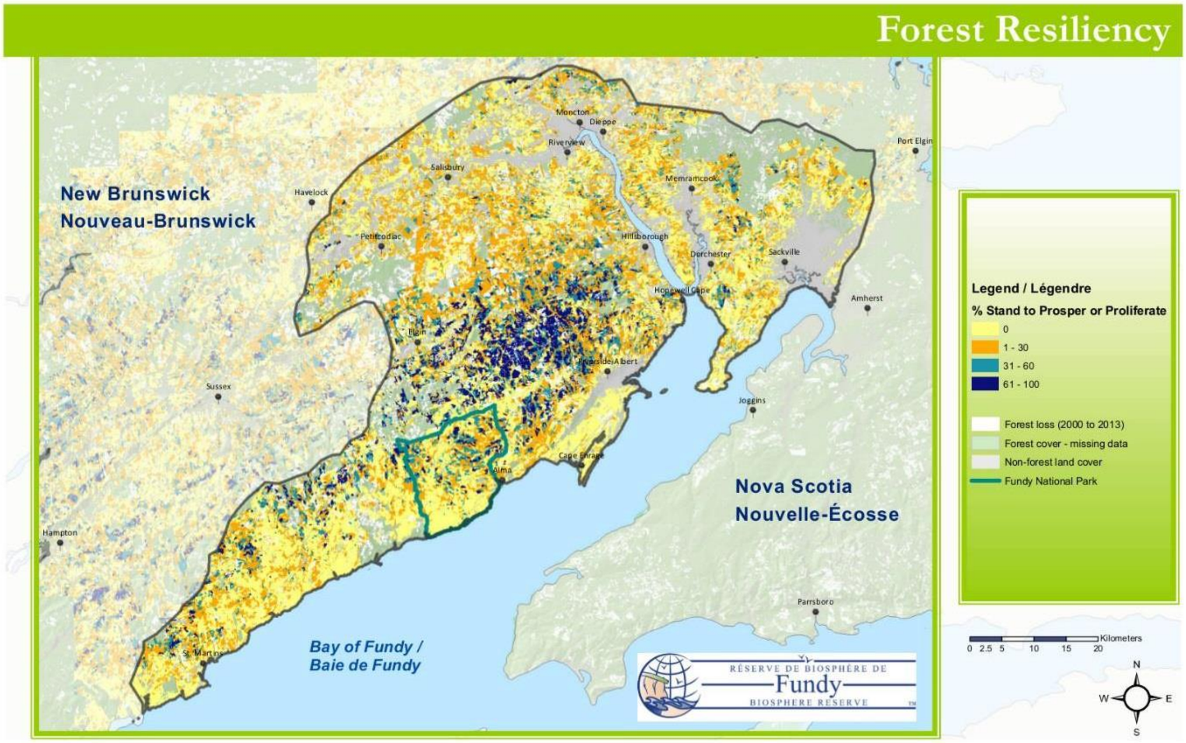


Figure 4. Based on the stand composition, and their predicted resilience, forest stands are mapped here to show the percentage of those stands that contain species that will either prosper or proliferate in the mid-term (2041-2070).

From these maps, we can see spatially across southeastern NB the pattern of decline to proliferation of species and forest stands, and identify which stands will experience the most change. Worrisomely, and likely due to decades of intensive borealization of the Acadian forest, there is a high percentage of stands in the region that are predicted to decline or merely persevere in the mid-term (2041-2070).

The FBR then used the above landscape resiliency maps, in combination with data layers from Nature Conservancy of Canada (NCC), Nature Trust of New Brunswick (NTNB), Canadian Parks and Wilderness Society: NB Chapter (CPAWSNB), and Two Countries, One Forest (2C1F) to identify landscape connectivity corridors. FBR then used the basic hexagons for resiliency map available through 2C1F, which is a measure of landscape resiliency based on physical and micro-climatic features. The higher levels of resiliency for both the 2C1F map and the FBR resilience maps were amalgamated to produce a new data layer, which created the basis for corridor layouts (Fig. 5).

Other features were considered in the layout of the corridors, specifically the locations of protected areas that needed network connectivity, inoperable or riparian zones not open to forestry operations, land ownership type and barrier avoidance (roads, culverts, railroads, etc.) in cases where possible. Essentially, the corridors map connects areas already protected, such as provincially-designated Protected Natural Areas (PNAs) and Fundy National Park, with one another via the forest stands with the greatest projected resilience. The map produced is meant to be a first draft to be critiqued and improved on over time.

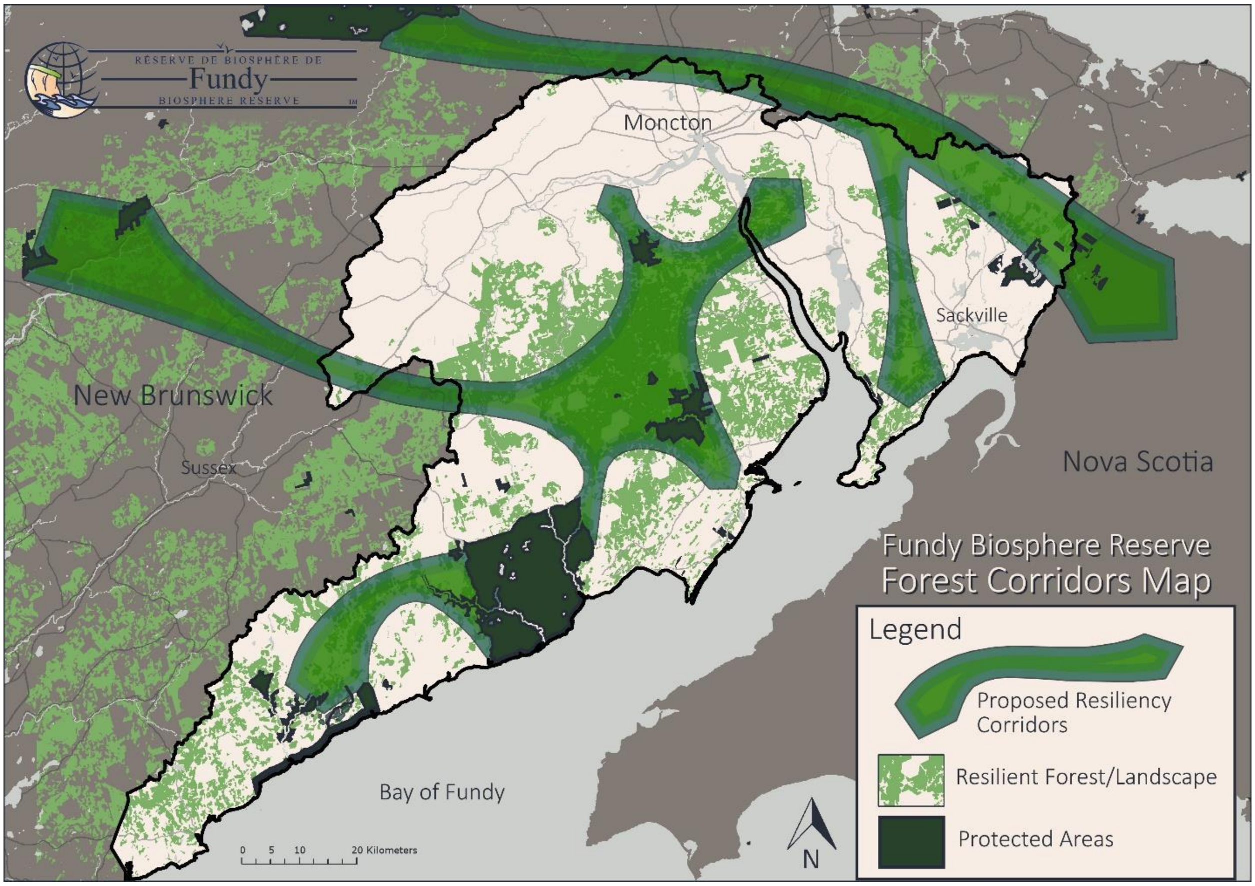


Fig. 5. Landscape connectivity corridors (superimposed medium green bands) connect the most climate change-resilient forest stands (background matrix of light green) to protected areas (dark green). These corridors include important wildlife pinch points, such as the Chignecto Isthmus and the north-south corridor through Anagance-Elgin.

The FBR considers the lands within the identified resilience corridors to be the most promising for conservation, restoration, and increased landscape resilience to climate change. The FBR advocates prioritizing land acquisition for conservation within those corridors, and moving toward increased climate adaptation by planting within them the most climate change-resilient tree species.

Discussion

Even in using different climate change models and in covering different areas of the AFR, there seems to be consensus from the three reviewed research projects' results on which species will do well, and which ones will do poorly, as the climate changes. This, in turn, gives confidence that we can collectively proceed with actions that target increasing climate change-resilience in the forests of the AFR.

Of the species that were investigated by one or more of the above research projects, twenty-three of them are projected to have moderate (persevere) to high (prosper or proliferate) resilience to climate change (Table 5) and are likely to still persist in the AFR by 2100. Only nine species had consensus from all three research projects, and so evidence is very strong that they will likely persist in the long-term (2011-2100): eastern hemlock, eastern white cedar, red maple, red oak, red spruce, sugar maple, white ash, white pine, and yellow birch. Of those species, only four are likely to increase in growth and distribution: red maple, red oak, white ash, and white pine. Another fourteen species were identified by one or two (but not all three) of the research projects as having moderate to high resilience to climate change: American beech, American mountain ash, balsam poplar, black cherry, bur oak, butternut, ironwood, mountain maple, mountain paper birch, pin cherry, serviceberry, silver maple, striped maple, and white elm.

That means this list provides the best possible list of priority species when considering actions on-the-ground to increase resiliency and adaptation in the forest.

Table 5. Species that are likely to exhibit moderate to high climate change resilience in the long-term (2011-2100). This estimate (*) likely underestimates the effects of beech bark disease in the region and (**) likely underestimates the overall abundance of sugar maple (see article for details).

Native Tree Species	**FBR**	**Taylor *et al.***	**Bourque & Hassan**	**Conclusion**
American Beech (*Fagus grandifolia*)	Prosper	Increase*	-	
American Mountain Ash (*Sorbus americana*)	Persevere	-	-	
Balsam Poplar (*Populus balsamifera*)	Persevere	-	-	
Black Cherry (*Prunus serotina*)	Prosper	-	-	
Bur Oak (*Quercus macrocarpa*)	Persevere	-	-	
Butternut (*Juglans cinerea*)	Persevere	-	-	
Eastern Hemlock (*Tsuga canadensis*)	Persevere	Unclear	Persevere	**Persevere**
Eastern White Cedar (*Thuja occidentalis*)	Persevere	Unclear	Decline	**Isolated patches?**
Ironwood (*Ostrya virginiana*)	Proliferate	-	-	
Mountain Maple (*Acer spicatum*)	Persevere	-	-	
Mountain paper Birch (*Betula cordifolia*)	Prosper	-	-	
Pin Cherry (*Prunus pensylvanica*)	Persevere	-	-	
Red Maple (*Acer rubrum*)	Proliferate	Increase	Proliferate	**Proliferate**
Red Oak (*Quercus rubra*)	Prosper	Increase	Proliferate	**Proliferate**
Red spruce (*Picea rubens*)	Decline	Decrease	Persevere	**Isolated patches?**
Serviceberry (*Amelanchier canadensis*)	Persevere	-	-	
Silver Maple (*Acer saccharinum*)	Persevere	-	-	
Striped Maple (*Acer pensylvanicum*)	Persevere	-	-	
Sugar Maple (*Acer saccharum*)	Persevere	Decrease**	Persevere	**Persevere**
White Ash (*Fraxinus americana*)	Persevere	Increase	Proliferate	**Prosper**
White Elm (*Ulmus americana*)	Prosper	-	-	
White pine (*Pinus strobus*)	Prosper	Increase	Prosper	**Prosper**
Yellow Birch (*Betula allenghaniensis*)	Decline	Unclear	Persevere	**Isolated patches?**

In terms of taking actions to increase resilience and adaptation at the landscape scale, it makes greatest sense to focus strategically on the landscape corridors that were identified by FBR. The lands within those corridors already have the greatest potential for adequately increasing climate change resilience and adaptation, while simultaneously addressing other challenges around habitat conservation and ecosystem services.

Conclusions

Consensus of this kind among research results challenges us to collectively identify next which forest stands should be prioritized for conservation, and which for targeted adaptation management. How to improve stand-level resiliency with appropriate climate-adaptive forest management (e.g. silvicultural prescriptions to modify stand composition, planting resilient tree species) also becomes one of the next challenges.

The most obvious avenues of action, therefore, to address the low resilience of the Acadian forest in the Maritime provinces are:

3. Climate-adaptive silviculture: much needed is a suite of silviculture prescriptions that manage the forests composition to become more diverse and more resilient to climate change (i.e. adaptation), and these prescriptions are needed for a variety of stand ages and conditions; and,
4. Widespread forest conservation, strategic corridors: it is critical to pull as many forested lands out of the industrial forestry process as possible. What few remaining stands of mixed old Acadian forest need to be protected and managed for long-term resilience, and younger stands need to be replanted and/or managed for long-term resilience. Strategically, focusing on protecting lands within the habitat connectivity corridors should take first priority.

References

Bourque, C. P.-A. and Hassan, Q. K. 2008. Projected impacts of climate change on species distribution
in the Acadian Forest region of eastern Nova Scotia. Forestry Chronicle: 84 (4), 553 – 557.

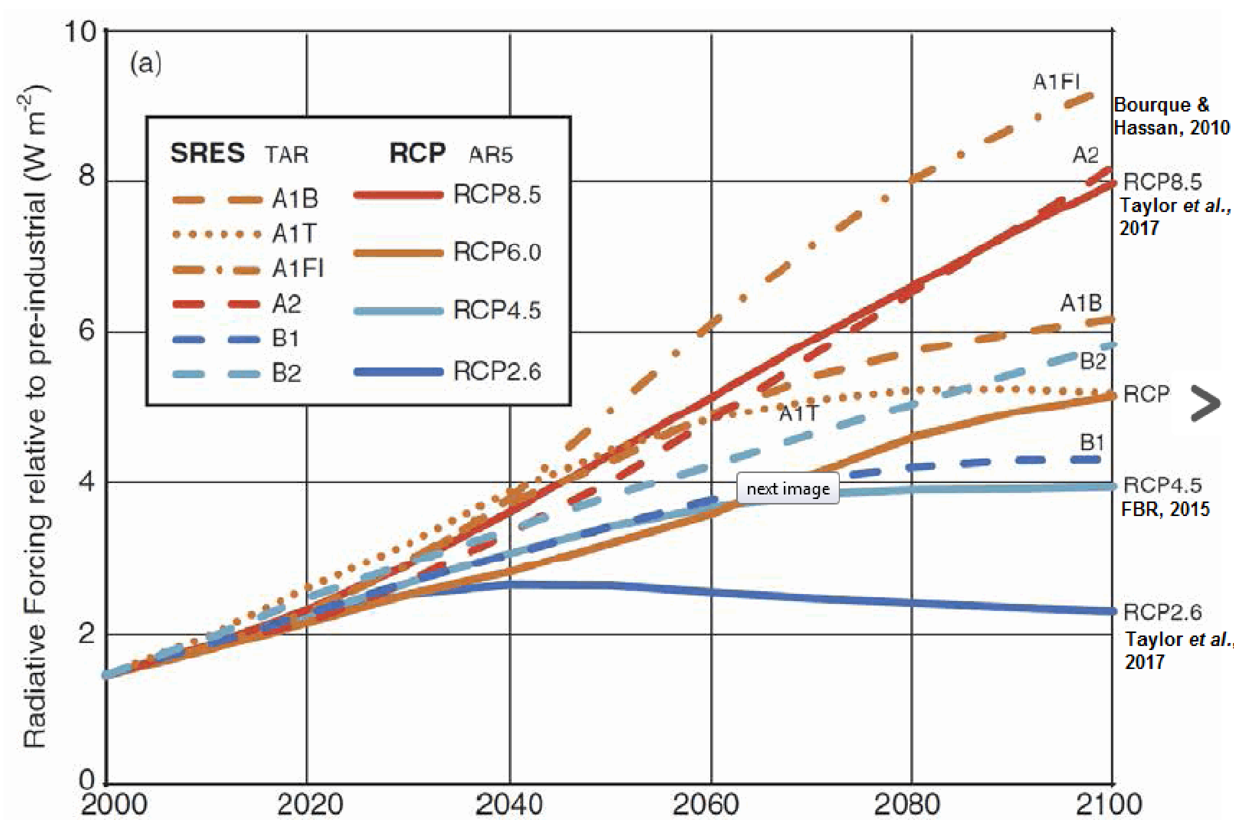
Bourque, C. P.-A. and Hassan, Q. K. 2010. Modeled potential tree species distribution for current and future climates for Prince Edward Island, Canada. https://www.google.ca/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0ahUKEwiTwuaso4LYAhWxUN8KHRRJB3wQFggqMAA&url=https%3A%2F%2Fwww.princeedwardisland.ca%2Fsites%2Fdefault%2Ffiles%2Fpublications%2Fclimate_change_2010._pei_full_report.pdf&usg=AOvVaw3yf8S-H3VajAPQ47gNObsi. Accessed on December 4, 2017.

Fundy Biosphere Reserve. 2015. Forests of the Future in the Fundy Biosphere Reserve: Climate Change Resiliency of Tree Species in the Fundy Biosphere Reserve Region. http://www.fundy-biosphere.ca/en/home/forests-of-the-future.html. Accessed on April 7, 2015.

Taylor, A. R., Boulanger, Y., Price, D. T., Cyr, D. McGarrigle, E., Rammer, W., Kershaw, J. A. Jr. 2017. Rapid 21st century climate change projected to shift composition and growth of Canada's Acadian Forest Region. Forest Ecology & Management. (405) 284 – 294.

Appendix I. Comparison of various climate change models

"Business-as-usual" models, such as SRES A1F1 and RCP 8.5 indicate the intensity of effects if climate change continues largely unchecked, with approximately a 4.9°C median temperature anomaly over pre-industrial levels by 2100. In comparison, "moderate" models like SRES B1 and RCP 4.5 include some analysis of climate change mitigation efforts, which would produce a 2.4°C median temperature anomaly over pre-industrial levels by 2100. The most aggressive climate change mitigation actions are modeled in RCP 2.6, which are predicted to still produce 1.5°C median temperature anomaly over pre-industrial levels by 2100. Each of the three studies reviewed in the body of this document used different models, as indicated in the graph below.



Projected radiative forcing (W ^m-2) over the 21st century from the SRES and RCP scenarios. Draft Figure 1-4 from IPCC AR5 WGII, Chapter 1.
Image 2 of 4

Appendix II. Fundy Biosphere Reserve, 2015.

Appendix III. Bourque & Hassan, 2010.